Technical Report HL-95-18
December 1995

US Army Corps of Engineers
Waterways Experiment Station

Ship Navigation Simulation Study, Southern Branch of the Elizabeth River, Norfolk, Virginia

by *Dennis W. Webb, Larry L. Daggett*

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Prepared for U.S. Army Engineer District, Norfolk

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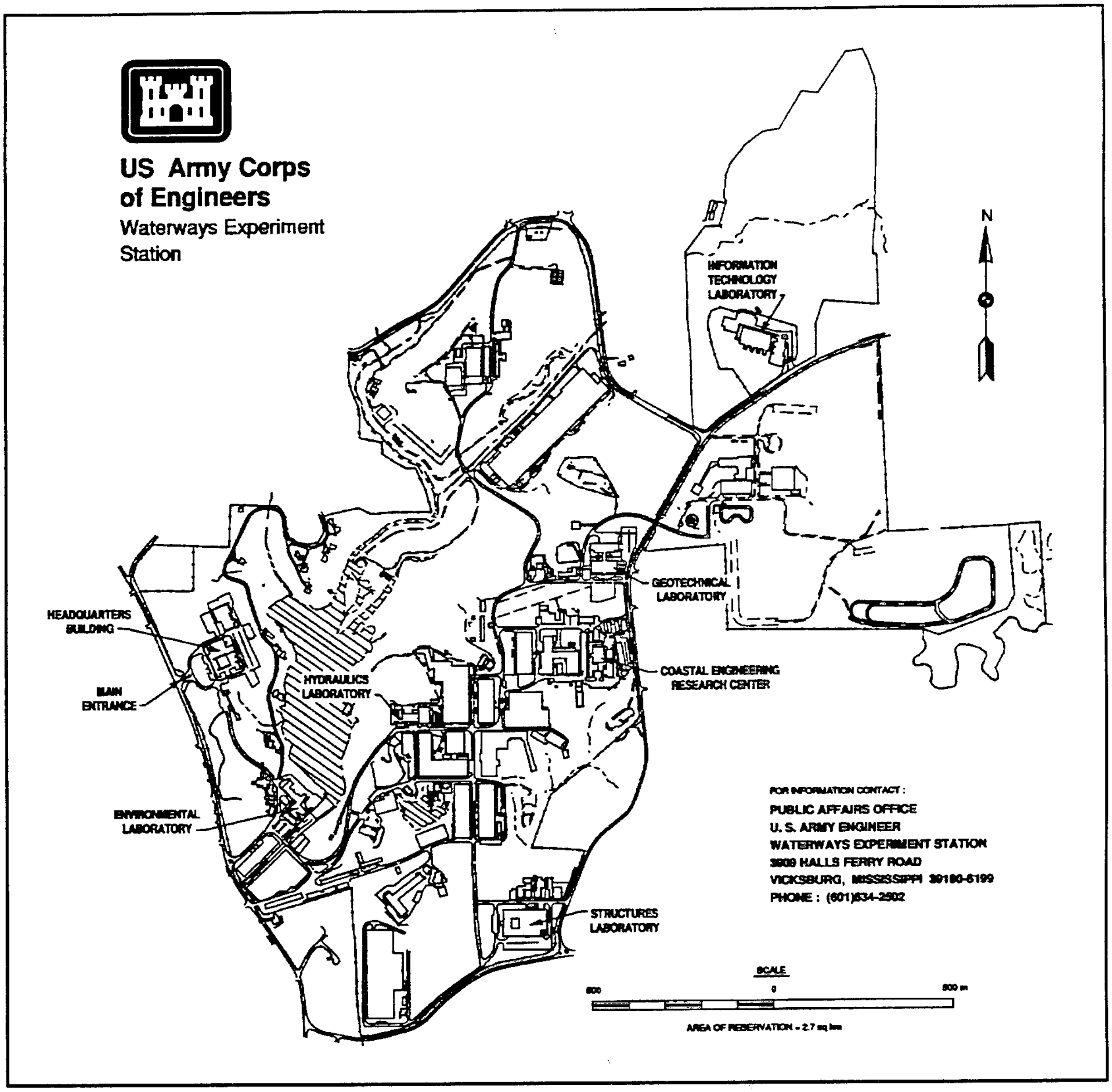
U.S. Army Corps of Engineers
Waterways Experiment Station
3909 Halls Ferry Road
Vicksburg, MS 39180-6199

Final report

Prepared for U.S. Army Engineer District, Norfolk
Norfolk, VA 23510-1096



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Preface

This investigation was performed by the Hydraulics Laboratory of the U.S. Army Engineer Waterways Experiment Station (WES) for the U.S. Army Engineer District, Norfolk (NAO). The study was conducted with the WES research ship simulator. NAO provided survey data of the prototype area. Current modeling was conducted by the Estuarine Processes Branch, Estuaries Division, Hydraulics Laboratory, WES. The study was conducted during the period July 1988-June 1988.

The investigation was conducted by Mr. Dennis W. Webb and Dr. Larry L. Daggett of the Navigation Branch, Waterways Division, Hydraulics Laboratory, under the general supervision of Messrs. Frank A. Herrmann, Jr., Director of the Hydraulics Laboratory; Richard A. Sager, Assistant Director of the Hydraulics Laboratory; and Marden B. Boyd, Chief of the Waterways Division. Other Waterways Division personnel involved in the study were Ms. Donna Derrick and Ms. Michelle Thevenot.

Acknowledgment is made to Mr. Richard Klien and Mr. Sam McGee, Engineering Division, NAO, for their cooperation and assistance at various times throughout the investigation. Special thanks should go to McAllister Brothers Towing, Newport News, VA, for access to an outbound ship and for furnishing professional pilots to conduct ship simulator tests on the WES ship simulator. Special thanks also go to the independent pilots who participated in the testing program.

At the time of publication of this report, Director of WES was Dr. Robert W. Whalin. Commander was COL Bruce K. Howard, EN.

Conversion Factors, Non-SI to SI Units of Measurement

Non-SI units of measurement used in this report can be converted to SI units as follows:

Multiply	By	To Obtain
degrees (angle)	0.01745329	radians
feet	0.3048	meters
horsepower (550 foot-pounds (force) per second per ton (force))	83.82	watts per kilonewton
knots (international)	0.5144444	meters per second
mile (U.S. statute)	1.609347	kilometers

1 Introduction

Navigational uses of Chesapeake Bay in the Norfolk area are of great importance to the Nation and the local community. Due to its naturally protected harbors, the Norfolk area has historically been the home port of naval activities since colonial times. Commercially, Norfolk has played a major role in east coast bulk shipping for many years. Its closeness to the Appalachian coal fields and connecting rail lines has helped it become the largest coal exporting port in the United States. However, with the current trends toward deeper draft bulk cargo vessels and an ever-increasing demand for United States coal, Norfolk may lose some of the competitive advantage. There are currently vessels calling on Norfolk that must carry partial loads to navigate through the existing channels. Since the majority of the cargo passing through Norfolk is high in volume and low in price, the efficient use of shipping is crucial to bring profits. Unless the harbor is deepened, future deep-draft vessels may be forced to use other ports.[1]

The Elizabeth River is the southernmost part of the Norfolk Harbor channel. The Norfolk Harbor channel joins with the 55-ft Newport News Channel to provide access to the Chesapeake Bay via the 55-ft Thimble Shoal Channel and to the Atlantic Ocean.[2]

Proposed Channel Improvement

The proposed improvements in the Elizabeth River channel (Figure 1), which extend south from Lamberts Point to the Gilmerton Bridges, are described as follows:[3]

a. Increasing the depth of the Elizabeth River and the Southern Branch of the Elizabeth River between Lamberts Point (river mile 9) and the

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1 David R. Richards and Michael R. Morton. (1983). "Norfolk Harbor and channels deepening study; Report 1, Physical model results," Technical Report HL-83-13, U.S. Army Engineer Waterways Experiment Station, Vicksburg, MS.

2 A table of factors for converting non-SI units of measurement to SI units is found on page 5.

3 U.S. Army Engineer District, Norfolk. (1980). "Norfolk Harbor and Channels, Virginia-Deepening and disposal feasibility report," Norfolk, VA.

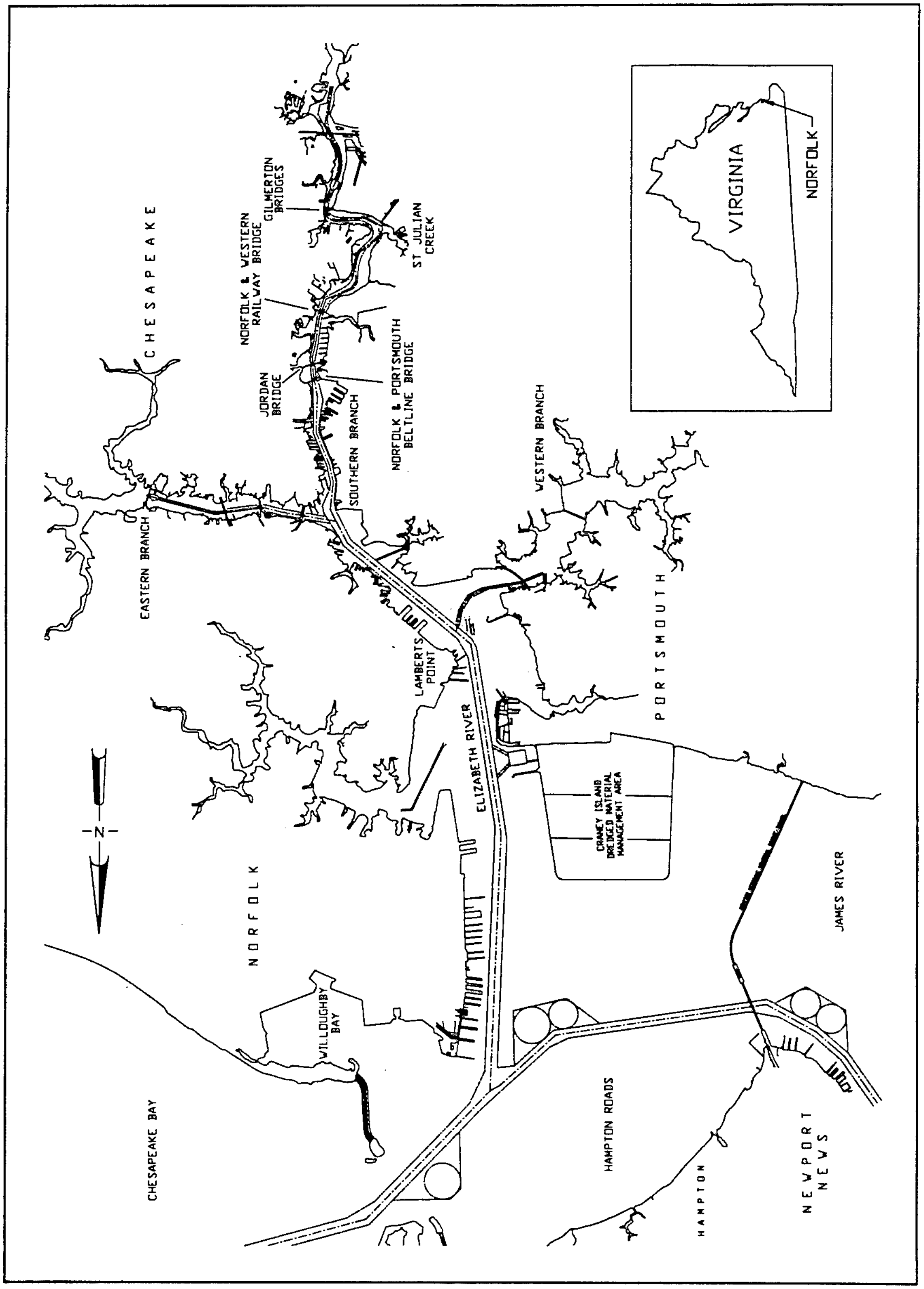

Figure 1. Project vicinity map

Norfolk and Western Railway Bridge (river mile 15) from 40 to 45 ft below mean low water (mlw) over its existing 375- to 750-ft width.

b. Increasing the depth of the Southern Branch of the Elizabeth River between the Norfolk and Western Railway Bridge (river mile 15) and the Gilmerton Bridges at U.S. Routes 460 and 13 highway crossings (river mile 17.5) from 35 to 40 ft below mlw over its existing 250- to 500-ft width, and providing a new 800-ft turning basin at the terminus of the channel improvement.

These depths are project depths and do not include advance maintenance or dredging tolerance. The actual depths for the proposed new channels with the advance maintenance and dredging tolerance should be 3 ft deeper.[1]

Purpose and Scope of Investigation

The purpose of the ship simulator investigation was to determine the effect of deepening the navigation channel in the Elizabeth River and the Southern Branch of the Elizabeth River, and to investigate the location and size of the turning basin. Proposed improvements were evaluated by comparing runs made under existing conditions with those made under plan conditions. In addition to deepening the existing channel, a channel widening south of the Norfolk and Western Railway Bridge was tested and evaluated at the suggestion of local pilots.

The Elizabeth River study reach was divided into three study areas for simulation purposes based on channel dimensions, ship sizes, type of ship traffic, and the navigation problem being addressed. Each study reach overlapped its adjacent study reaches. The following study reaches were implemented on the U. S. Army Engineer Waterways Experiment Station (WES) ship simulator, as shown in Figure 2:

a. Scenario A includes the Elizabeth River from Lamberts Point to the mouth of the Eastern Branch of the Elizabeth River. This study reach is presently 40 ft deep and is to be deepened to 45 ft. Two-way ship traffic was simulated in this reach.

b. Scenario B includes the Southern Branch of the Elizabeth River from its mouth to the Norfolk and Western Railway Bridge. This study reach is presently 40 ft deep and is to be deepened to 45 ft. This reach provides for one-way ship traffic with tug assistance.

c. Scenario C includes the existing 35-ft channel from Norfolk and Western Railway Bridge to the Gilmerton Bridges. This study reach is

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[1] Richards and Morton, op. cit.

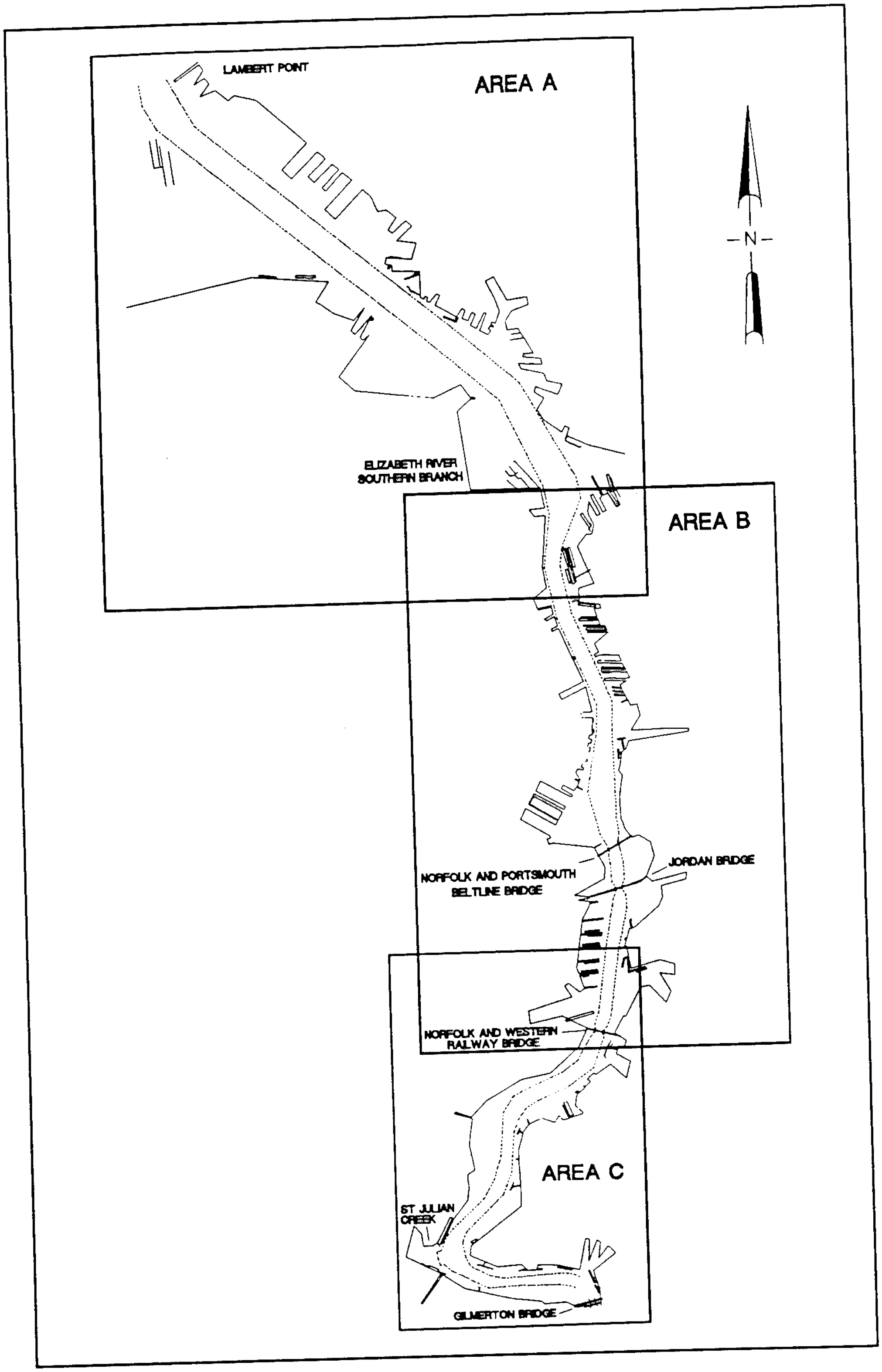

Figure 2. Simulated areas

presently 35 ft deep and is to be deepened to 40 ft. This reach provides for one-way ship traffic with tug assistance and testing of the 800-ft turning basin

2 Data Development

In order to simulate the study area, it is necessary to develop information relative to five types of input data:

a. The channel database contains dimensions for the existing channel and the proposed channel modification. It includes the channel cross sections, slope angle, overbank depth, initial conditions, and autopilot trackline and speed definition.

b. The visual scene database is composed of three-dimensional images of principal features of the simulated area, including the aids to navigation, buildings, and bridges.

c. The radar database contains the features for the plan view of the study area.

d. The ship data file contains characteristics and hydrodynamic coefficients for the test vessels.

e. The current pattern data in the channel include the magnitude, direction, and depth of the current for each cross section defined in the channel database.

Channel

The information used to develop the channel database came from the hydrographic survey charts furnished by the U.S. Army Engineer District, Norfolk. This was the latest information available concerning depths, dimensions, and bank lines of the channel. State planar coordinates as shown on the annual survey were used for the definition of the data.

The ship simulator model uses eight equally spaced points to define each cross section. At each of these points, a depth and current magnitude and direction are required. For each cross section, the width and right and left bank slopes are required. These data were obtained from the hydrographic survey data provided by the Norfolk District for use in the main program for

calculating bank suction forces. The cross-section layout for the three study reaches of the Elizabeth River simulation are shown in Figures 3-5.

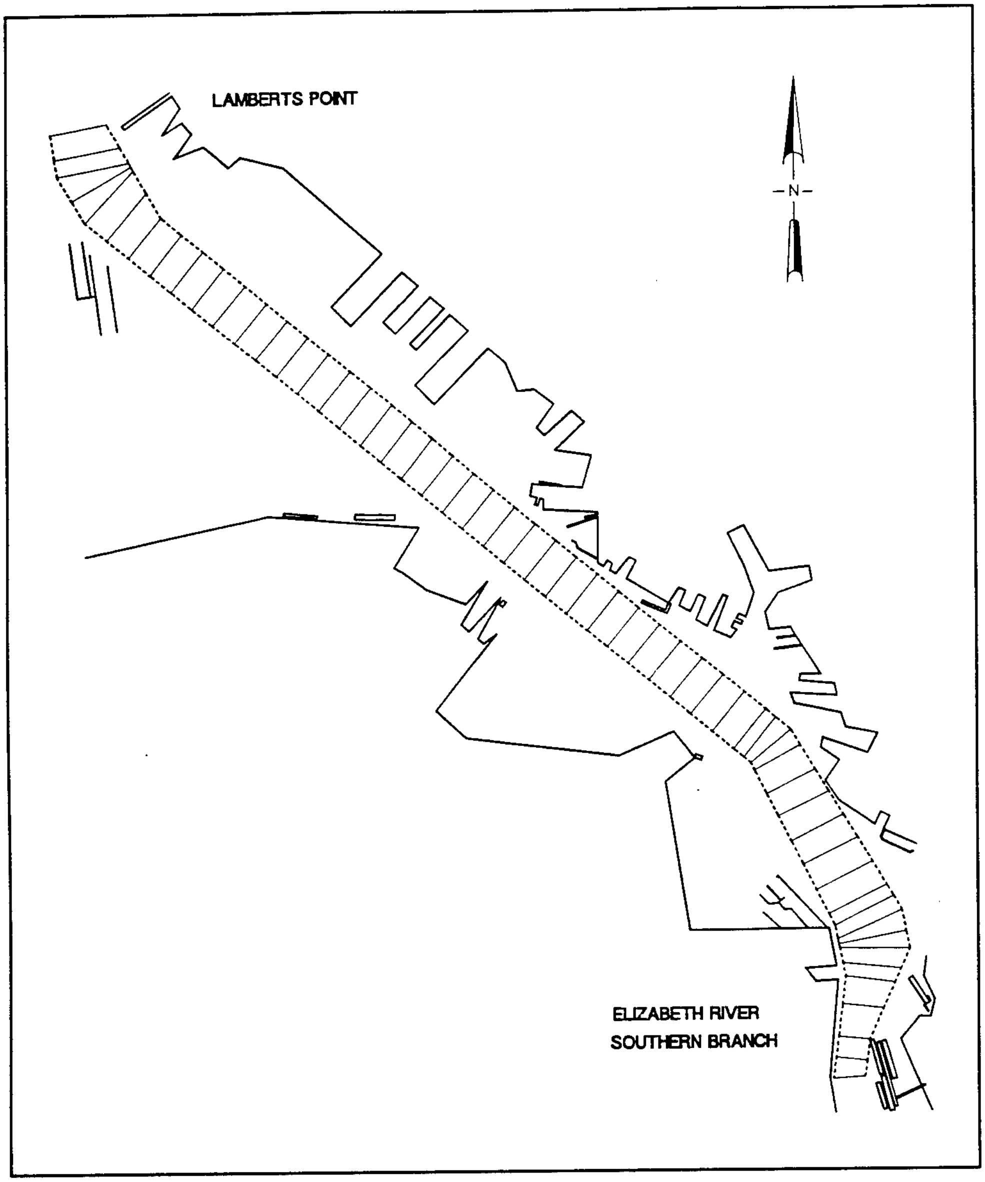

Figure 3. Cross-section layer, Area A

The channel side slope and overbank depth are used to calculate bank force. The shallower the overbank and the steeper the side slope, the greater the computed bank force. The hydrodynamic module that computes bank force requires that the overbank depth be less than the channel bottom. It is important to note that the overbank depth is used only to calculate the bank force and does not necessarily mean that the vessel grounds in that area. A small difference (1 to 2 ft) in channel bottom and overbank depth produces negligible bank forces and moments.

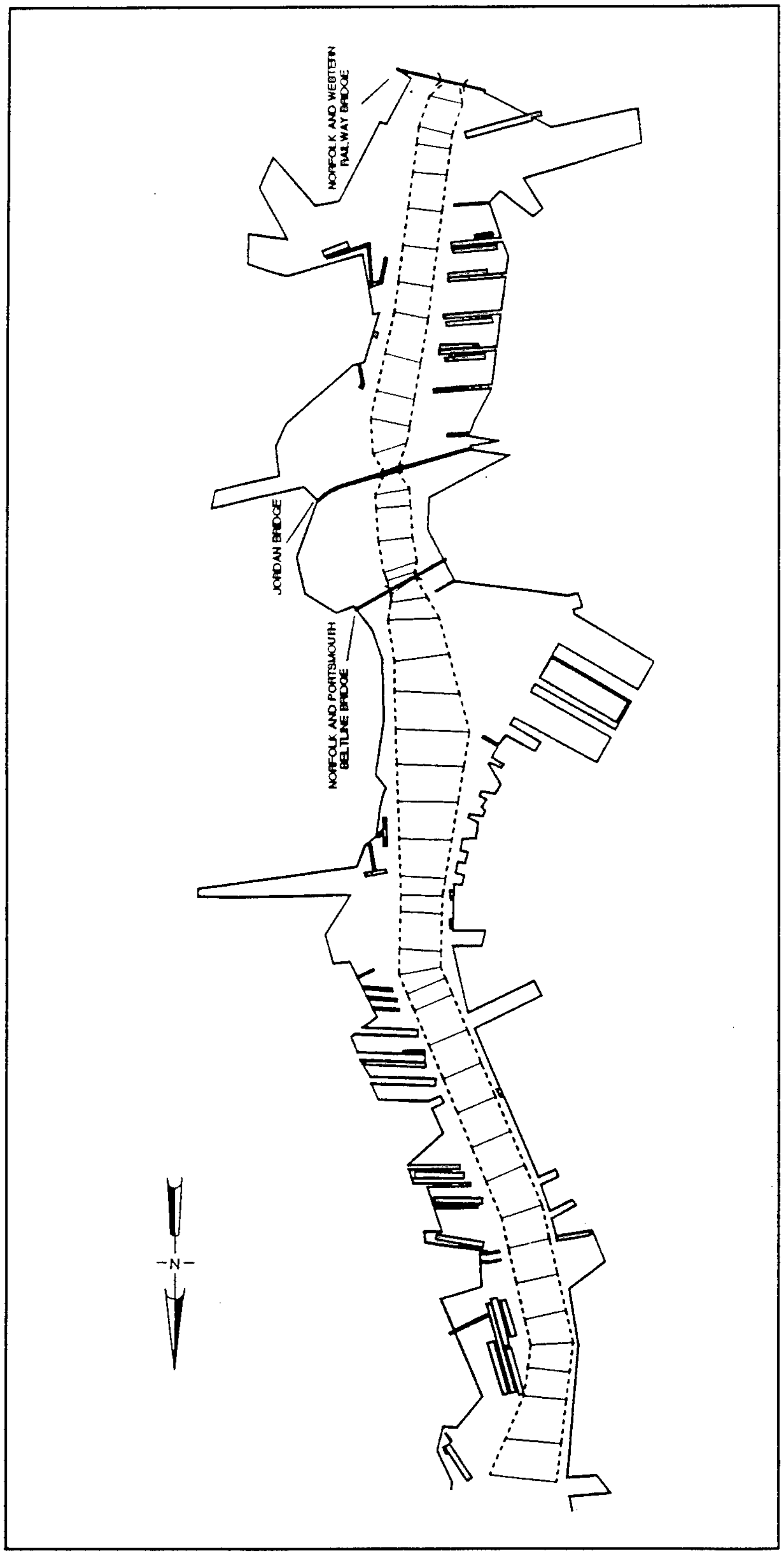

Figure 4. Cross-section layer, Area B

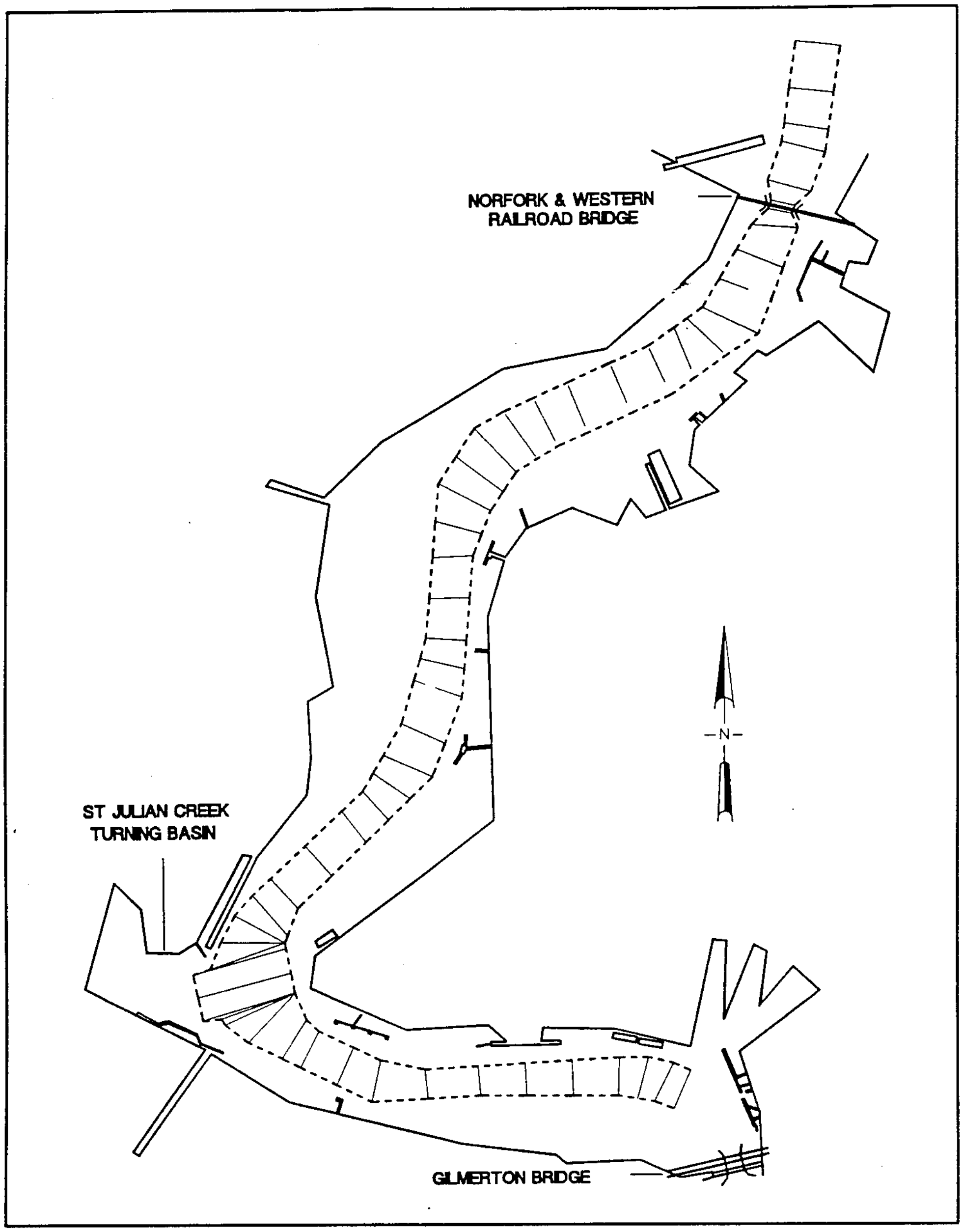

Figure 5. Cross-section layer, Area C

The channel depths at each of the eight points were provided by the mathematical model that computed the current magnitudes and directions.

Visual Scene

The visual scene database was created from the same maps and charts noted in the discussion of the channel source. Aerial and still photographs and pilot's comments obtained aboard a transiting ship during a reconnaissance trip to Norfolk constituted other sources of information for the scene. These

allowed inclusion of the significant physical features and also helped determine which, if any, features the pilots use for informal ranges and location sightings.

All aids to navigation such as buoys, channel markers, bridges, buildings, docks, docked vessels, towers, and tanks were included in the visual scene.

The visual scene is generated in three dimensions: north-south, east-west, and vertical elevation. As in the development of the channel database, the state planar coordinate system was used. As the ship progresses through the channel, the three-dimensional picture is constantly transformed into a two-dimensional perspective graphic image representing the relative size of the objects in the scene as a function of the vessel's position and orientation and the relative direction and position on the bridge for viewing. The graphics hardware used for the Norfolk project was a stand-alone computer (Silicon Graphics-Iris 2300) connected with the main computer to obtain information for updating the viewing position and orientation. This information includes parameters such as vessel heading, rate of turn, forward and lateral velocity, and position. Also, the viewing angle is passed to the graphics computer for the look-around feature on the simulator console, which encompasses only a 40-deg arc. This feature simulates the pilot's ability to see any object with a turn of his head. The pilot's position on the bridge can also be changed from the center of the bridge to any position wing to wing to simulate the pilot walking across the bridge to obtain a better view, e.g., along the edge of the ship from the bridge wing.

It may be noted that the creation of a scenario for the project area is very demanding in terms of engineering judgment. The goal of the scenario is to provide all the required data without excessive visual clutter, taking into account the finite memory storage and computational resources available on the minicomputer.

Radar

The radar database is used by the Geneisco graphic image generator to create a simulated radar for use by the test pilots. The radar database contains x- and y-coordinates that define the border between land and water. The file also contains coordinates for any structure that is built or extends into the water such as bridges and aids to navigation. In short, these data define what a pilot would actually see on a shipboard radar. The radar image is a continuously updated view of the vessel's position relative to the surrounding area. (Three different ranges of 0.5 mile, 0.75 mile, and 1.5 miles were programmed for the pilot to choose the scale needed.)

Current

A current database contains current magnitude and direction at eight points across the channel at each of the cross sections defined in the channel. Channel bottom depths are also given at each of these eight points and are included in the channel definition.

For simulation purposes, all current in the Elizabeth River was assumed to be tidal driven with no freshwater inflow.

Current data were modeled by WES using the TABS-2 model. This modeling technique is discussed in Berger et al.[1] The model provided information on depth, velocity, and current direction. Results from this model were evaluated and data were selected from the time-steps providing the maximum flood current and the maximum ebb current. These currents were fairly small and none had a magnitude of more than one knot.

All tests were conducted with "fair tide"; that is, the vessels were always running with the current. Based on discussions with area pilots prior to testing, this was found to be the more difficult or "worst case" condition. Therefore, all inbound runs were conducted with flood tide and all outbound runs were conducted with ebb tide.

Test Ship

Two design ships were used for pilot testing. Each vessel required a ship database consisting of the ship characteristics and coefficients used in the hydrodynamic program for calculating forces acting upon the vessel used in the testing program. In addition, the bow of the ship from the ship bridge was also seen in the visual scene by the pilot. Visual images of the ship bows for both design ships had been created for previous studies at WES.

A 880- by 138-ft bulk carrier was used as the design ship in Areas A and B. This vessel was loaded to 40 ft for the existing condition and 45 ft for the proposed channel. For two-way traffic, the "ghost ship" was of the same size and draft as the piloted vessel.

The design ship for Area C was of the Panamax class. This ship, a 775- by 106-ft bulk carrier, was loaded to 35 ft for the existing condition and 40 ft for the proposed channel.

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1 R. C. Berger, Jr., Samuel B. Heltzel, Robert F. Athow, Jr., David R. Richards, and Michael J. Trawle. (1985). "Norfolk Harbor and channels deepening study; Report 2, Sedimentation investigation; Chesapeake Bay hydraulic model investigation," Technical Report HL-83-13, U.S. Army Engineer Waterways Experiment Station, Vicksburg, MS.

The drafts selected were based on conversations with local pilots during the reconnaissance trip of 21 September 1988 and during simulation validation. These drafts reflect current ship handling practices. An adequate underkeel clearance is maintained at these drafts due to maintenance overdredging and a minimum stage of 1 ft above mlw at the time selected for both the ebb and flood current.

Wind

No wind forces were placed on the ship during testing. The pilots stated that they do not experience wind problems due to the draft of the vessels and tall buildings blocking the wind from the river.

Tugs

Tests conducted in Areas B and C were run with four 3,500-hp tugboats available for the pilot's use. A tug was located at the port bow, starboard bow, port stern, and starboard stern. The tugs either pushed or pulled along a line normal to the vessel. The power applied by the tug was either none, one-fourth, half, three-fourths, or full. Because the simulator tugs do not occupy any physical space in the simulation, the pilots were instructed not to use tugs if they felt that the vessel was in an area too confined to allow a tug alongside. The pilots were also instructed to limit the number of tugs that they used to the number they felt would be available in an actual transit. Tugs can be moved from one location to another on the ship in real life, but not on the simulator. A real tug can, for example, work on the bow for part of the transit and move to the stern for another, but simulator tugs must be prepositioned at both points. Therefore, using four tugs on the simulator might require only two tugs in prototype transits.

Pilots

A vessel operating in the reach simulated for this study actually falls under the command of two different pilot organizations. A licensed member of the Virginia Pilots Association is required to be on every commercial ship while it is transiting Virginia waters, while a docking pilot is generally in control of the ship while it is in the Southern Branch. The docking pilots are usually employed by one of the towboat companies. For inbound runs, these docking pilots usually board the vessel near the mouth of the Eastern Branch and take command until the vessel is docked. For outbound runs, they are responsible for undocking the ship and bringing it safely out of the Southern Branch, after which they turn over command to a Virginia Pilot and leave the vessel. The docking pilots are also in charge of turning the vessel.

During the reconnaissance trip, a meeting was held with representatives from WES, the Norfolk District, the Virginia Pilots Association, and two tugboat companies. At this meeting it was agreed that only docking pilots would be used for simulation testing. This was done to utilize their expertise in maneuvering through the Southern Branch and at turning the ships. Five docking pilots participated in the navigation study.

Involving the local professional pilots incorporated their experience and familiarity with handling ships in the study area in the project navigation evaluation.

3 Navigation Study

Validation

Validation of the simulation was conducted over a 4-day period with the assistance of a docking pilot licensed for the Elizabeth River. The following information is verified and fine-tuned during validation:

a. The channel definition.

(1) Bank conditions.

(2) Currents.

b. Wind forces.

c. The visual scene and radar image of the study area.

(1) Location of all aids to navigation.

(2) Location and orientation of the bridges.

(3) Location and orientation of the docks.

(4) Location of buildings visible from vessel.

Both design vessel models had been validated and used in previous simulations at WES.

To validate the reaction of the vessel to bank forces, several simulation runs were made with the vessel transiting the entire study area. Special attention was given by the pilot to the response of the ship to the bank forces. Problem areas were isolated, and the prototype data for these areas were examined. The values for the overbank depth, the side slope, or the bank force coefficient were then adjusted. Simulation runs were then undertaken through the problem areas, and if necessary, further adjustment was made. This process was repeated until the pilot was satisfied that the simulator response to the

bank force was similar to that of an actual vessel passing through the same reach in the prototype.

The vessel's reaction to current forces was verified by conducting several simulation runs over the entire study area. The pilot was instructed to pay attention to the current effects. He was satisfied that the vessel response to the currents was similar to responses he had experienced in real life.

To validate the reaction of the vessel to the "ghost ship" used in the two-way traffic scenarios, short transits were made in the passing area with the pilot paying careful attention to the response of his vessel to the other ship. The pilot did not feel that his vessel responded properly to meeting and passing the other ship. In response to this problem, the software module that calculates the effects of passing vessels was modified. After inclusion of the new passing module in the hydrodynamic software, the pilot was satisfied that the passing scenario was similar to that in real life.

A check of the visual scene and radar image of the study area occurred during validation of the other parameters. If the pilot noticed something missing or misplaced, this was checked against prototype information and corrected.

Test Conditions

The Elizabeth River testing schedule in the following tabulation was implemented on the WES ship simulator.

Tests were conducted in a random order. The test condition (Area A, B, or C; inbound or outbound; existing or plan) was chosen at random. The chosen condition was then tested and removed from the list of conditions. Once all conditions were tested, the list was repeated, again randomly. This was done to prevent prejudicing the results as would happen if, for example, all existing conditions were run prior to running the plans. The skill gained at operating the simulator could show the plans to be easier than they really are.

Prior to collecting the data from the actual test runs, a daily familiarization trial run was required from each of the pilots. These warm-up runs are not included in test analysis.

During each run, the characteristic parameters of the ship were automatically recorded every 5 seconds. These parameters included the position of the ship's center of gravity, speed, revolutions per minute (rpm) of the engine, heading, drift angle, rate of turn, rudder angle, and port and starboard clearances.

The simulator tests were evaluated based on pilot ratings, ship tracks, and statistical analysis of various ship control parameters recorded during testing. The following section will discuss these three methods of analysis.

Area	Direction	Plan	Description
A[1]	Inbound	0	The existing 40-ft channel
		1	The proposed 45-ft channel
	Outbound	0	The existing 40-ft channel
		1	The proposed 45-ft channel
B	Inbound	0	The existing 40-ft channel
		1	The proposed 45-ft channel
	Outbound	0	The existing 40-ft channel
		1	The proposed 45-ft channel
C	Inbound	0	The existing 35-ft channel
		1	The proposed 40-ft channel
		2	The proposed 40-ft channel widened upstream of the Norfolk and Western Railway bridge
	Outbound	0	The existing 35-ft channel with the St. Julian Creek Turning Basin
		1	The proposed 40-ft channel with the Plan 1 turning basin (Figure 6)
		2	The proposed 40-ft channel with the Plan 2 turning basin and the channel widened upstream of the Norfolk and Western Railway bridge (Figure 7)

[1] All plans in Area A simulated two-way traffic.

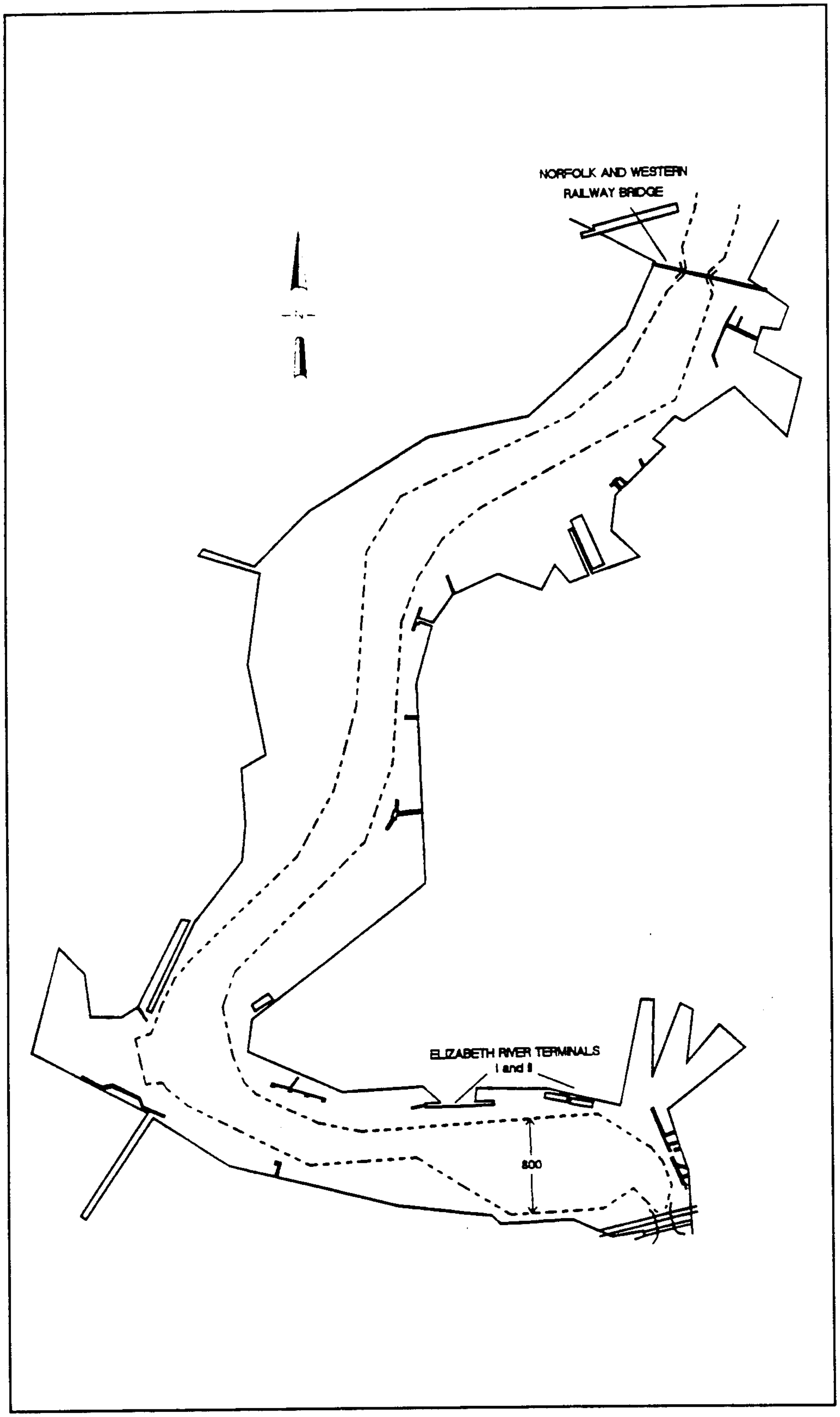


Figure 6. Plan 1 turning basin

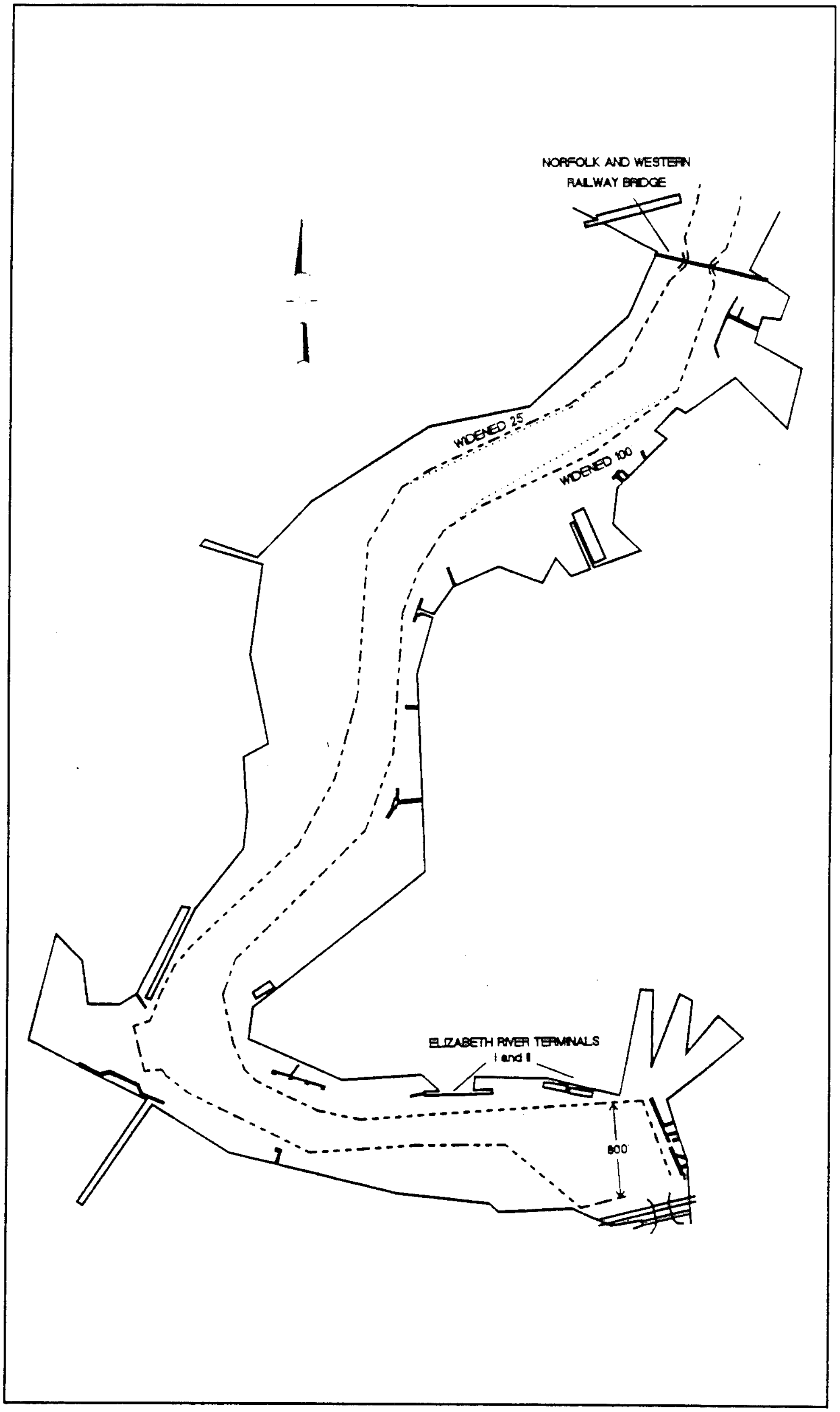


Figure 7. Plan 2 turning basin and widener

4 Study Results

Pilots' Ratings

To determine what the pilots thought about the simulator and the proposed channel deepening, two questionnaires were prepared to document their comments and rate the runs. One was given to the pilots after each run, and a final debriefing questionnaire was given after each pilot had completed his entire testing program. Pilots were asked to provide ratings for the three test areas in the simulation, as follows:

a. Area A. A bar chart of the pilot ratings for Area A is presented in Figure 8. These charts show that the pilots believed the 45-ft channel was safer than the 40-ft channel for inbound runs. However, the pilots thought the existing channel was safer in three out of the four categories for outbound runs. The existing channel and the proposed channel were rated close together for difficulty, attention required, and danger of hitting an object. The danger of grounding was rated significantly higher for the 45-ft channel with the pilot's main concern the turn to port off Town Point.

b. Area B. A bar chart of the pilot ratings for Area B is included as Figure 9. Analysis of these charts shows that, on the average, the pilots rated the proposed channel approximately one rating point safer in all four categories than the existing channel. However, the standard deviations show a wide scatter. For all ratings in Area B, the pilots believed that passing through the Norfolk and Portsmouth Belt Line Bridge and the Jordan Bridge was easily the most dangerous part of the test run.

c. Area C. A bar chart of the pilot ratings for Area C is shown in Figure 10. The charts show that the pilots rated the inbound runs for both 40-ft channel plans as more difficult than the existing channel; however, all ratings are nearly equal. Plan 2, with its channel widening, was rated as having a lesser danger of grounding than either the existing or Plan 1. For outbound runs the pilots rated the Plan 1 channel as much safer in all four categories than either the existing condition or Plan 2. Conversations with the pilots revealed that this difference would have been

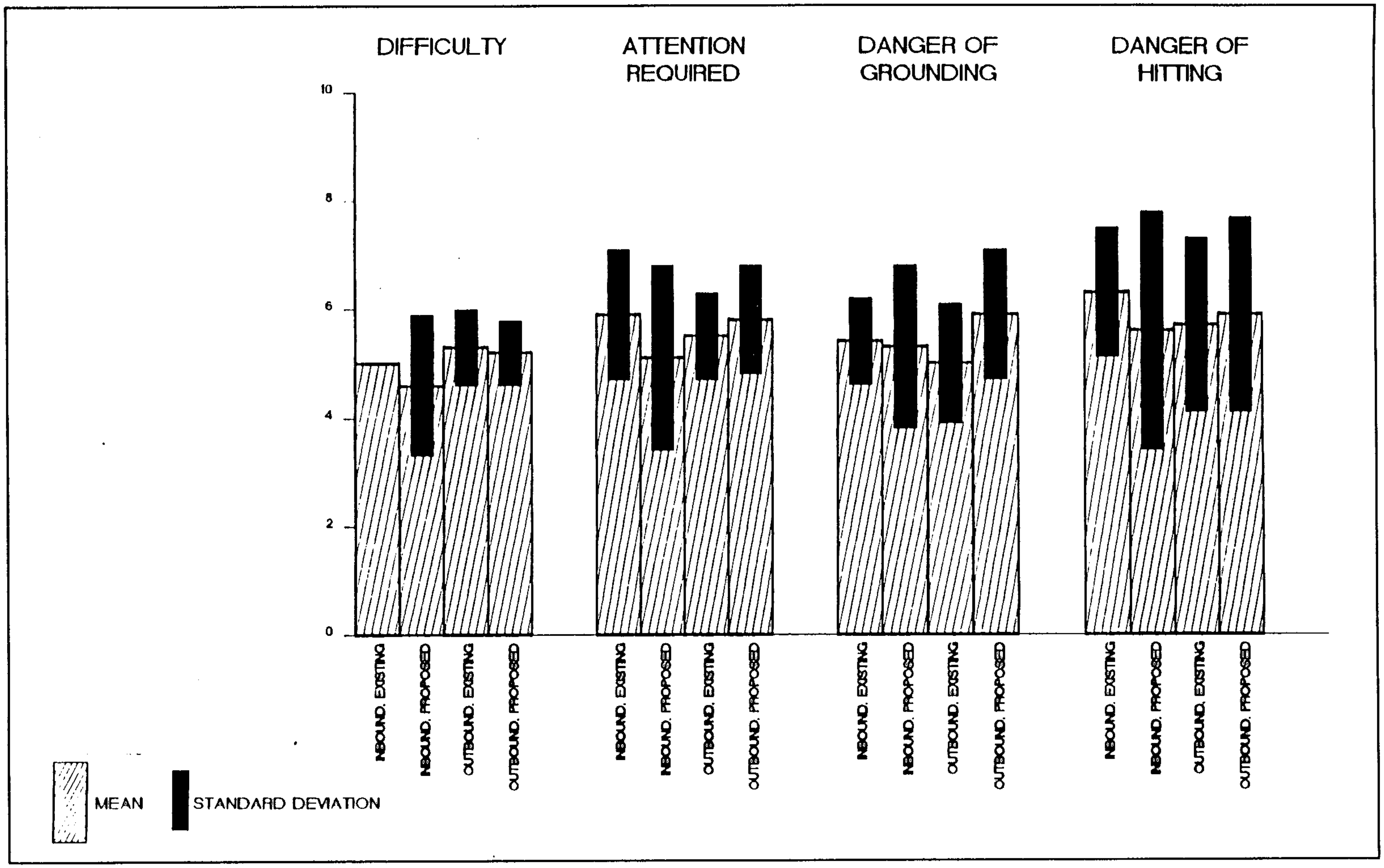


Figure 8. Pilot rating, Area A

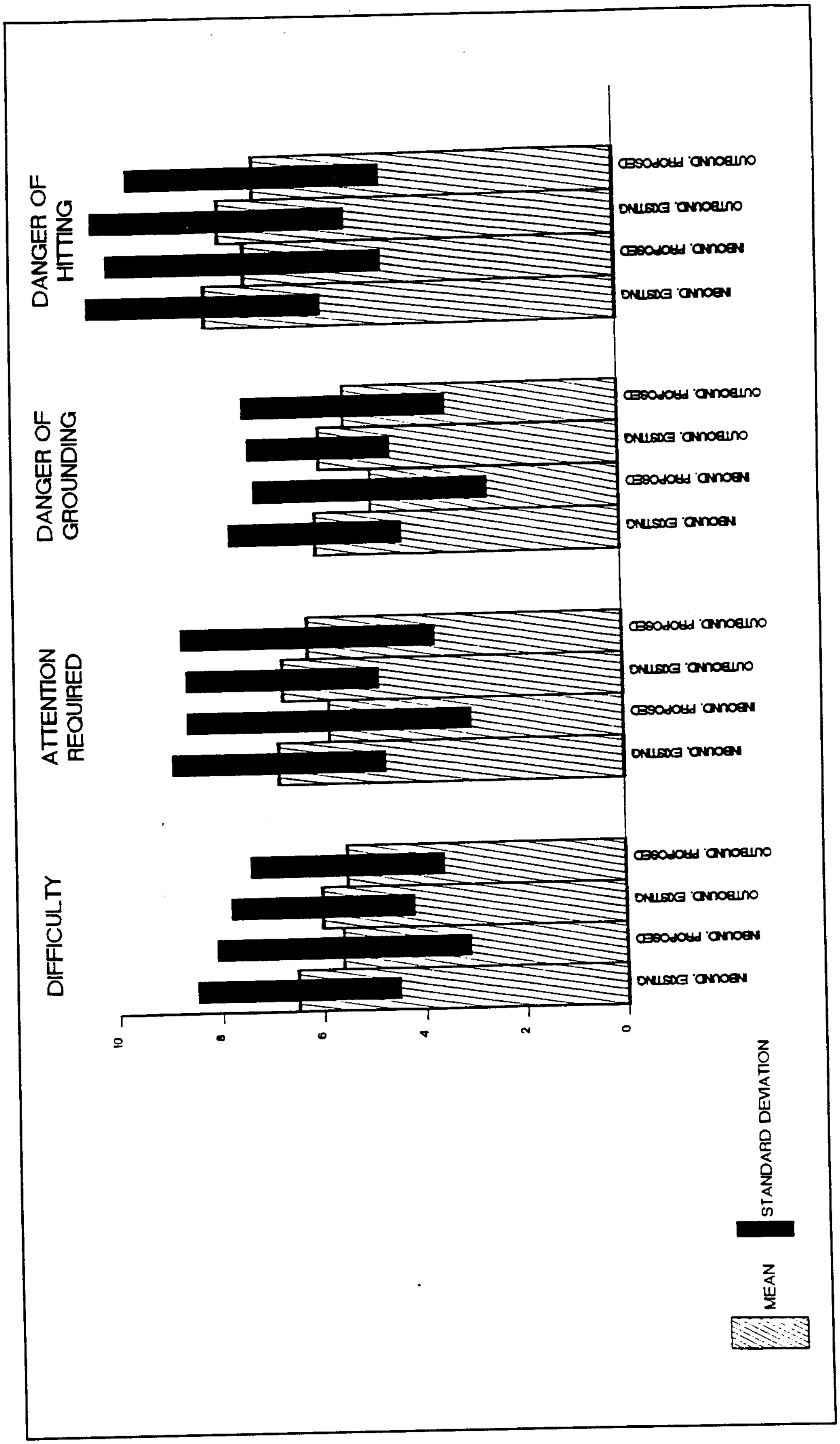


Figure 9. Pilot rating, Area B

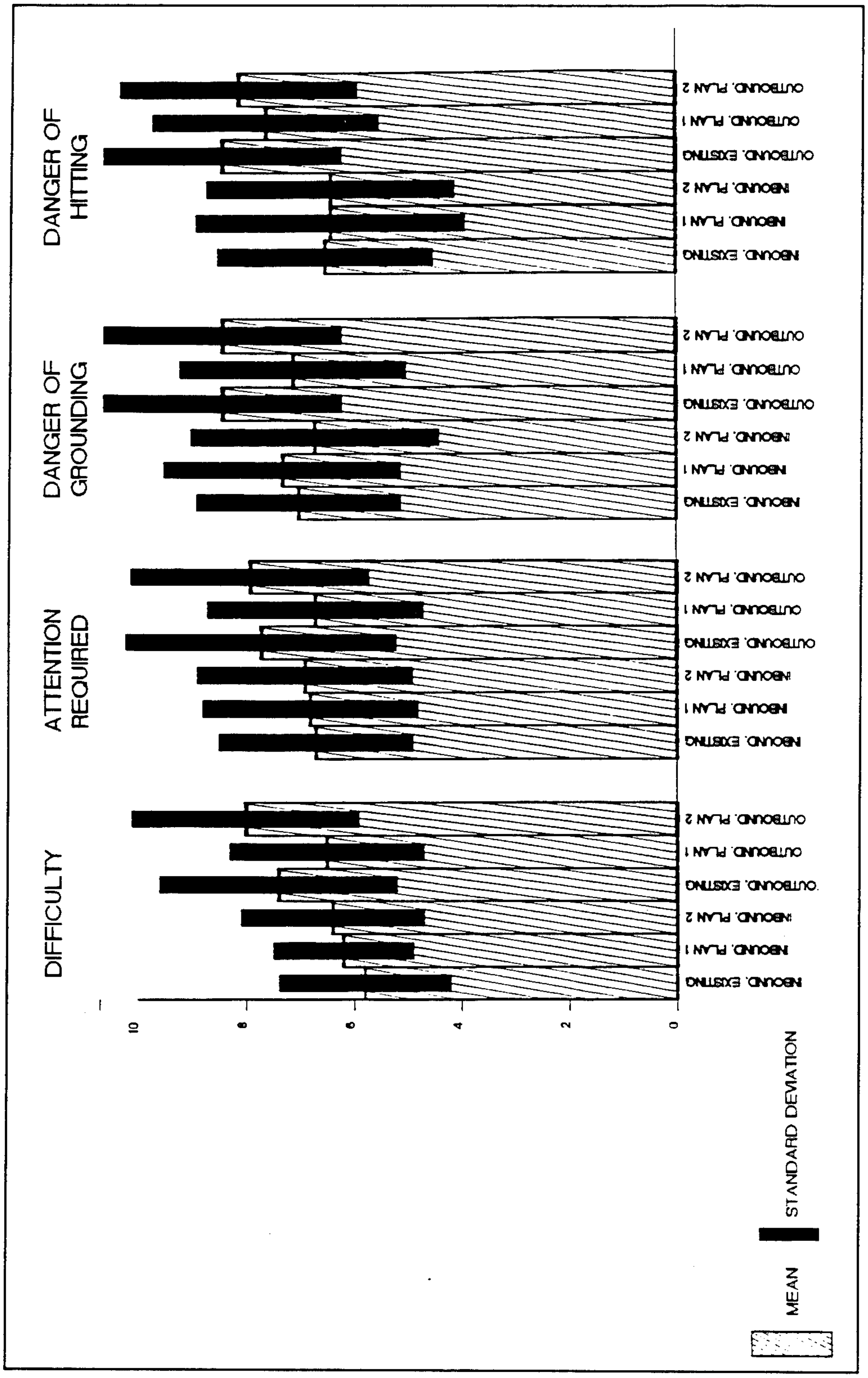


Figure 10. Pilot rating, Area C

even greater had the channel widening, which the pilots endorsed, been tested with the Plan 1 turning basin as opposed to the Plan 2 basin.

Final Questionnaire

After completing all test runs, the pilots completed a final questionnaire to give their opinions on the project as well as on the simulation. Some of the comments made by the pilots on the project are included with this report.

How will deepening the channel affect ship maneuverability and safety in all areas?

"The deeper channel should make passage safer. Ships should maneuver better in deeper water."

"The deeper channel will certainly make the maneuverability of a vessel more controllable."

"It will enable deeper ships to transverse the area with the same degree of safety that the 40-ft vessels have at present."

"With larger ships there is more care required in piloting."

Is there any difference in the bank force between the existing and the deepened channel?

"No."

"In order to navigate safely, you had to reduce speed, therefore reducing bank force. I noticed no difference at speed of 3 knots or less."

"It is reasonable to assume that a larger ship will encounter an increase in the affects of bank cushioning and suction; however, a pilot should take that into account when he is piloting a ship."

Is there any difference in the effect of the current between the existing and the deepened channel?

"No."

"Minor."

"Should be slightly more."

Did you have more difficulty passing through the Norfolk-Pacific Belt Line Bridge and the Jordan Bridge with the deeper draft vessel?

"I had trouble with the simulator on both the 40-ft and 45-ft in the bridges. I don't believe there would be any problem based on actual experience."

"No. I found passing through the bridges inbound to be extremely difficult in all inbound runs. The degree of difficulty was greater than that actually experienced in actual ship handling."

"The deepening of the draft should not cause any problem. As long as it does not come from a longer ship."

Does the channel widening at the outbound approach to the last turn before the Norfolk & Western Railway Bridge significantly aid both inbound and outbound runs?

"Yes."

"Yes, it gives more room in that reach."

"Yes, this is my preferred plan. I have had trouble with bank force in this area."

Are there any other specific areas that you feel should be widened?

"No."

"Just the existing turn basin if the new ones are not developed."

In response to this question, two pilots provided the maps shown in Figures 11-16. Figure 11 was provided by one pilot as his "wish list" channel. The other plots were provided as a series of possible widenings by another pilot. Figure 12 represents his minimum widening plan. Each successive figure shows his improvements to the previous plan, up to his "ideal" channel, Figure 16.

Which of the two proposed turning basins did you prefer, Plan 1 or Plan 2?

"Plan 1 allows more room for turning."

"I preferred the turning basin in Plan 1."
"Plan 1 is ideal!"

"Plan 1."

"Plan 1 allows for more room."

Do you have an alternate proposal for the location of a turning basin near the Elizabeth River Terminals?

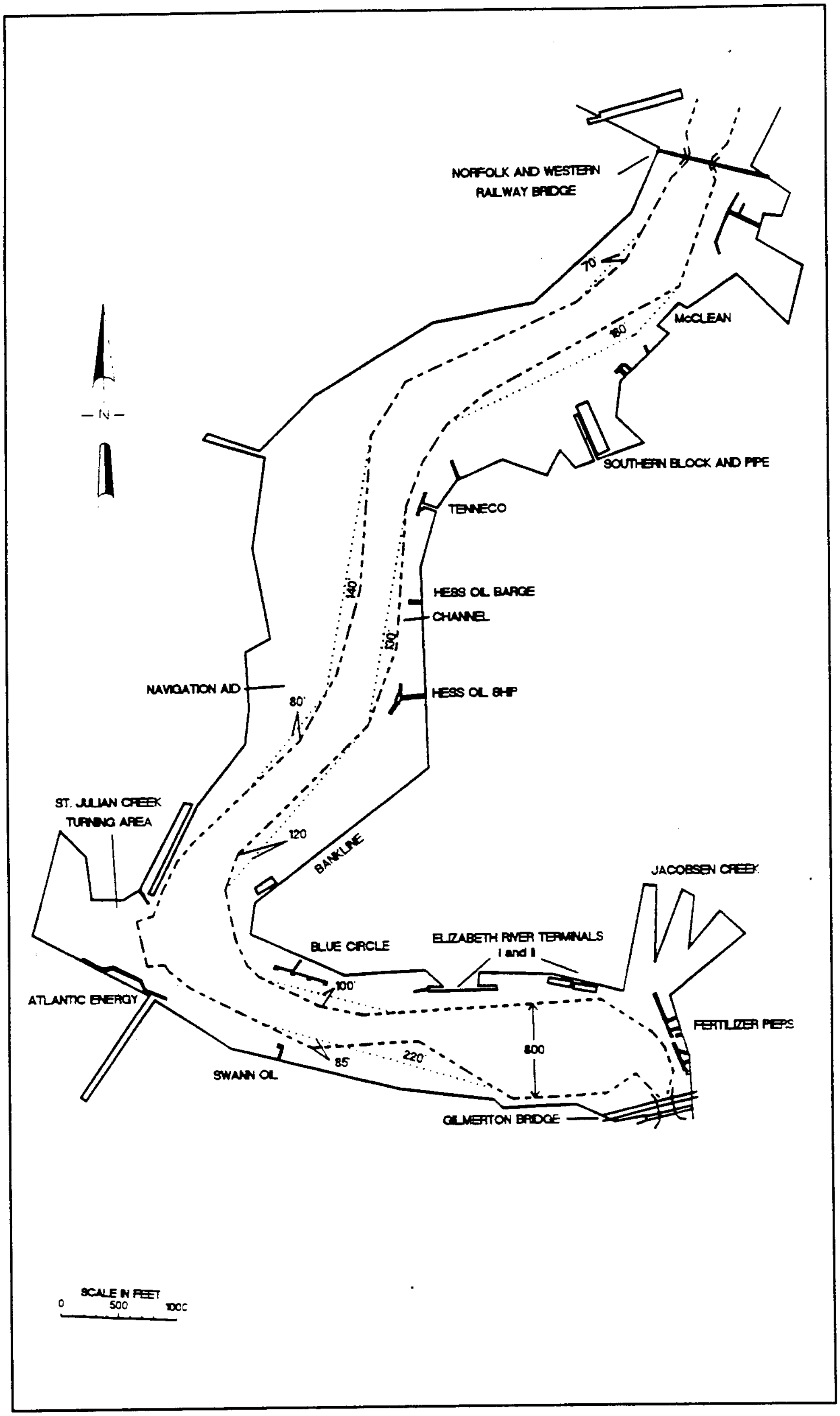


Figure 11. Pilot's recommendation 1

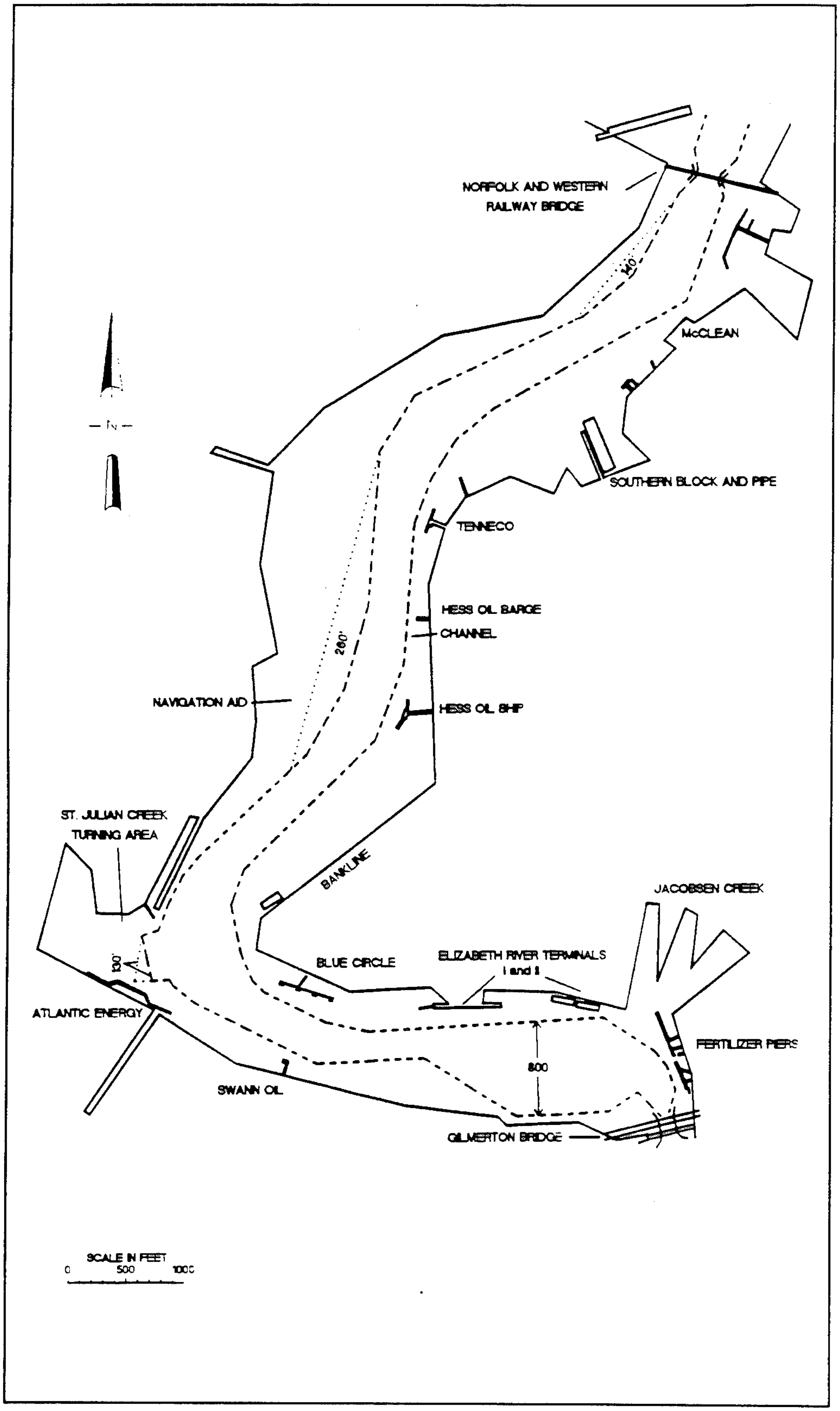


Figure 12. Pilot's recommendation 2

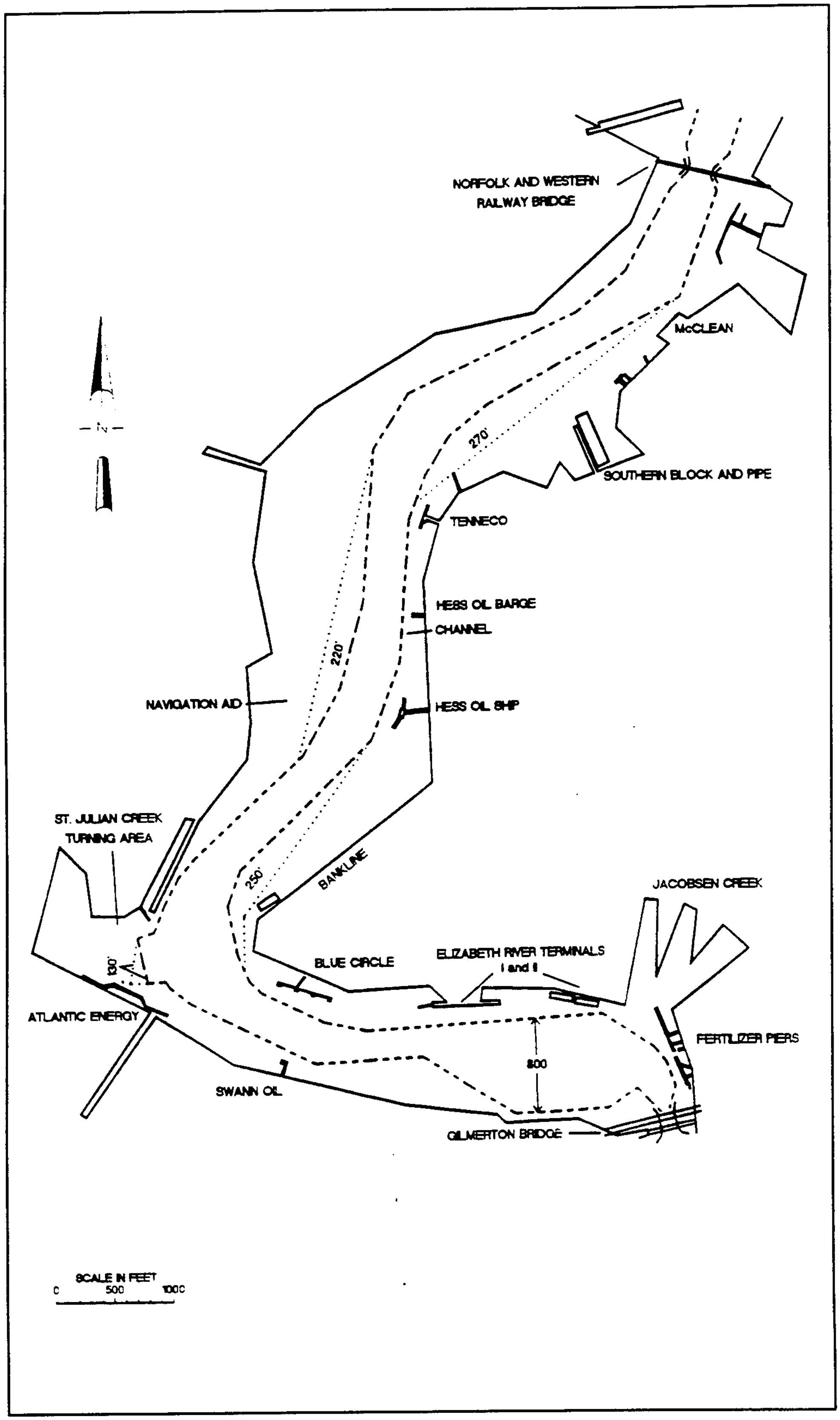


Figure 13. Pilot's recommendation 3

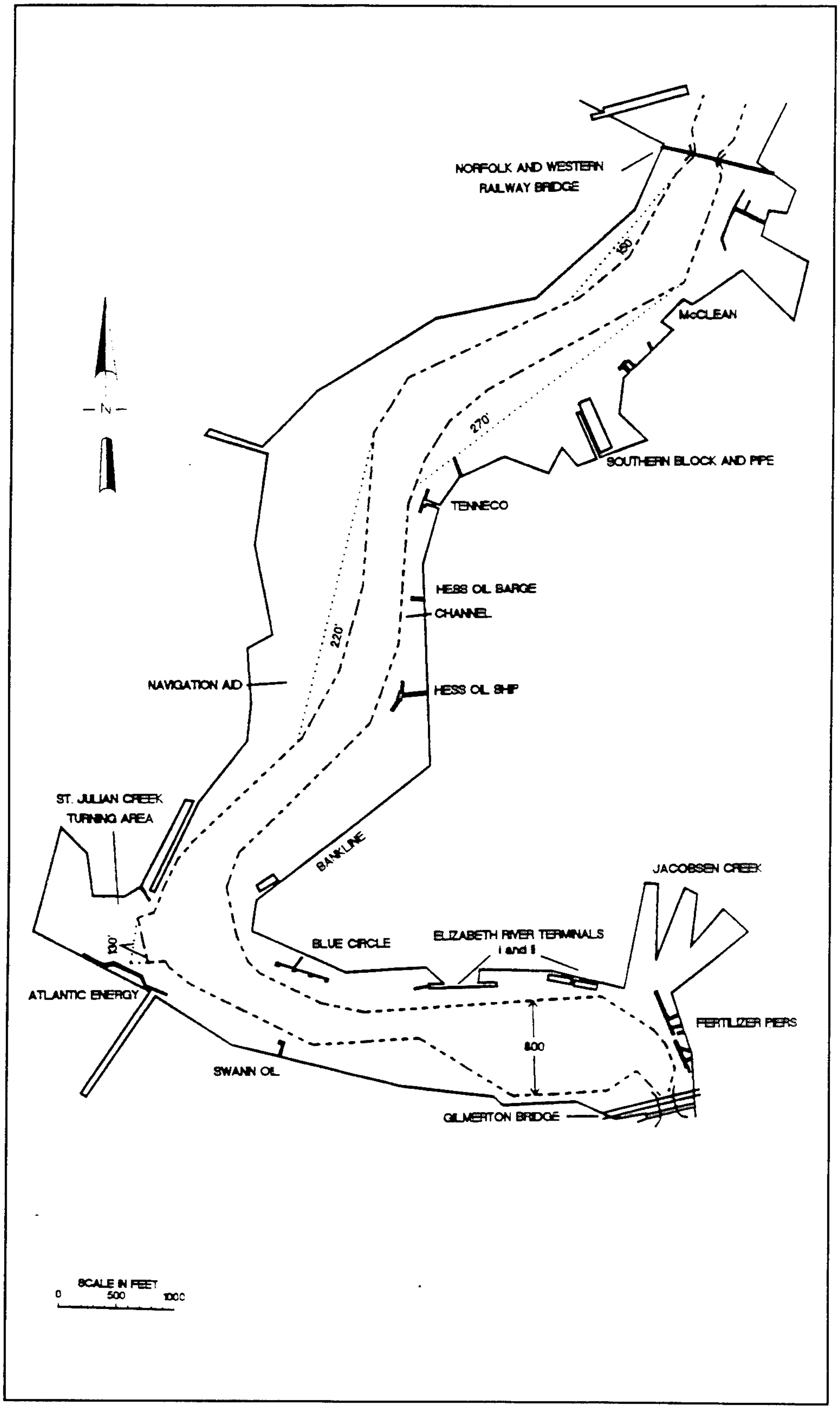


Figure 14. Pilot's recommendation 4

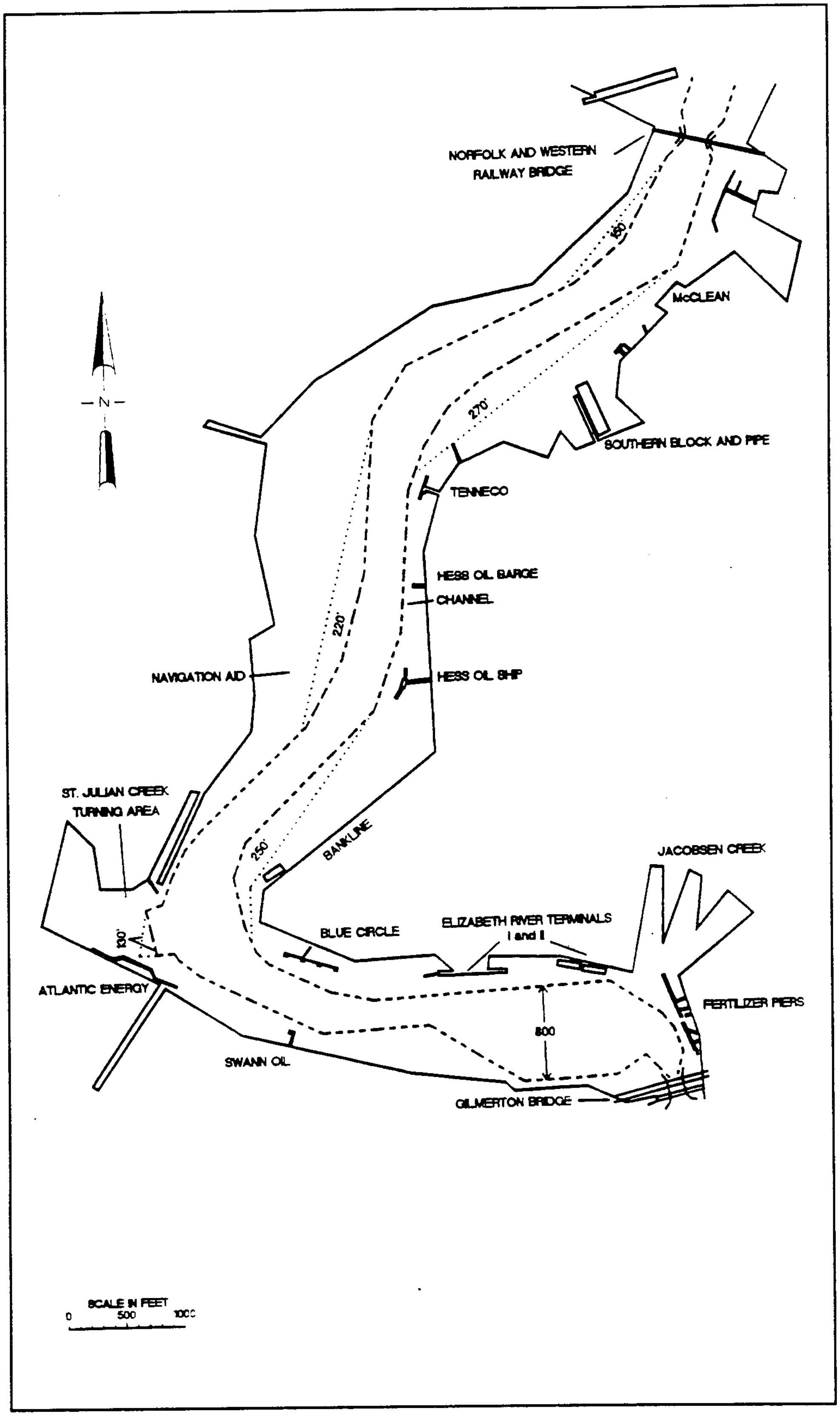


Figure 15. Pilot's recommendation 5

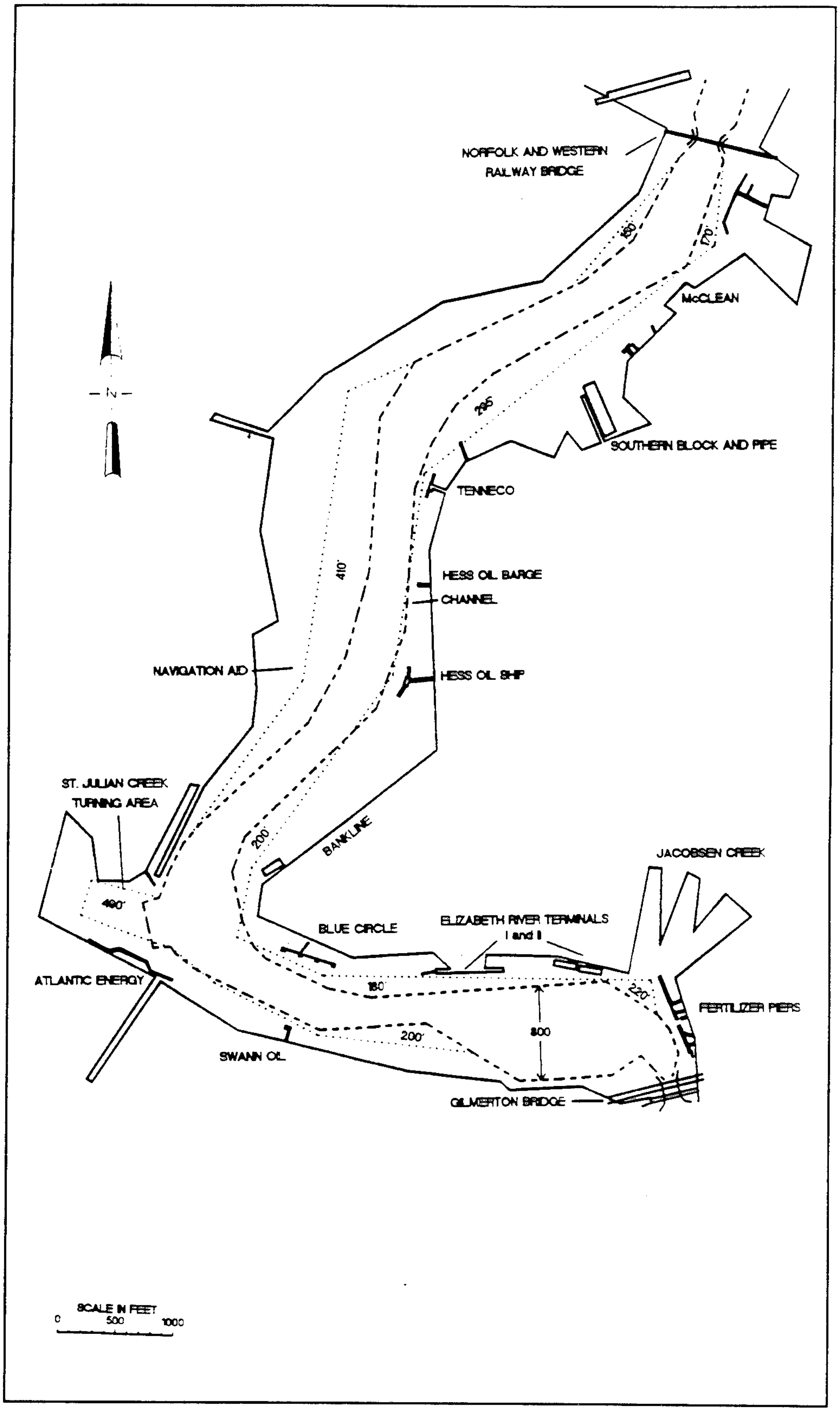


Figure 16. Pilot's recommendation 6

"Put the basin further west so the middle of the basin is between the berths at ERT."

Do you feel that the St. Julian Creek Turning Area could be abandoned?

"Yes."

"No, it should be made larger. Ships from Hess Oil and Swann Oil and Blue Circle Lime could be turned in this area safely."

"No."

Composite Ship Track Plots

A complete set of the composite ship track plots for the two channel test conditions is presented in Plates 1-38. For all track plots included in this report, as well as the discussion of those track plots, aids to navigation will be referred to as follows: G-11 = green light number 11; R-12 = red light number 12; C-13 = can buoy number 13; and N-14 = nun buoy number 14.

Ship track plots, Area A

Composite piloted ship track plots for the four channel conditions tested in Area A are presented in Plates 1-8. In order to show the track plots at a readable scale, Area A has been divided into two areas, A1 and A2. The "ghost ship" track-line is the path that the second vessel followed during the two-way traffic testing. The "ghost ship" tracks are shown in the area where the two vessels influenced each other. Lines running between the piloted ship and the "ghost ship" denote the location where the two ships were abreast. Each pilot was able to complete two runs of each test condition in Area A.

Inbound runs. Track plots for existing condition inbound runs for Area A are shown in Plates 1 and 2. These plots show that the pilots had little difficulty transiting the tested area under existing conditions. The pilots generally followed the same path without any near groundings or near collisions. Inbound run track plots for the proposed 45-ft channel for Area A are shown in Plates 3 and 4. These plots show two areas of concern. In the first area, near the degaussing station, one pilot nearly grounded by not turning sharply enough. This problem occurred on the pilot's first run under these conditions. However, the vessel did not actually ground, and the pilot did not have this problem on his second run under identical conditions through this reach. The second area of concern is just south of the Eastern Branch. One run was aborted just before the pilot crashed into the docked ship at the floating dry dock. The pilot stated that through his error, he did not begin his turn soon enough. This occurred on the pilot's first test on the simulator, and he did not have this problem on his second run under the same conditions. For runs conducted under both existing and proposed conditions, all pilots brought their

ships to the center of the two-way ship channel to make the turn to starboard required to enter the Southern Branch. If they had been meeting another vessel, this maneuver would have been impossible. Conversations with the area pilots indicate that if at all possible the pilots of the meeting vessels work together, so that the vessels pass in the straight reach and not in the bend.

Outbound runs. Track plots for existing condition outbound runs for Area A are shown in Plates 5 and 6. These plots show that most pilots had little difficulty transiting the tested area under existing conditions. The only problem occurred at the end of a pilot's first outbound run in Area A; he misunderstood that he was supposed to complete the turn at the end of the test. The pilots generally followed the same path, and there were no other near groundings or near collisions. Outbound run track plots for the proposed 45-ft channel for Area A are shown in Plates 7 and 8. These plots show that the pilots had little difficulty transiting the tested area for the proposed 45-ft channel. The pilots generally followed the same path, and there were no near groundings or near collisions.

Ship track plots, Area B

Composite piloted ship track plots for the four channel conditions tested in Area B are presented in Plates 9-28. As in Area A, Area B is shown as two areas, B1 and B2. A large-scale plot of each condition as the pilots transited the bridges has also been provided with these track plots. Each pilot was able to complete at least two runs of each test condition in Area B.

Inbound runs. In prototype inbound runs, Elizabeth River pilots generally pass through the Norfolk and Portsmouth Belt Line Bridge and the Jordan Bridge by swinging their vessel west into the naval shipyard and then keeping the ship on a constant radius going through the bridges. The pilots used this same approach on the simulator with mixed results. Several of the pilots had a problem with the two three-dimensional bridges represented on a two-dimensional screen. Since the pilots begin their turn into the bridges based on the physical location of their ship, any difficulties with interpreting the simulator displays could cause serious problems passing through these bridges. One cure for this problem is increased pilot familiarity with the simulator. Therefore, track plots of repeat runs only have been included for analysis along with the track plots of all inbound runs in Area B. Also, none of the pilots brought their vessels as far into the shipyard as possible, with none of the ships coming closer than 200 ft to the eastern corner of the shipyard. Although this area may not be needed for through transits, area pilots use the naval shipyard for turning vessels.

Track plots for existing condition inbound runs for Area B are shown in Plates 9-14. Track plots of all runs in the existing 40-ft channel (Plates 9-11) show that the pilots had great difficulty passing through the Norfolk and Portsmouth Belt Line Bridge and the Jordan Bridge. These plots show that the eastern fender of the Jordan Bridge was struck several times. All runs stayed

to the eastern side of the channel between Amoco Oil dock and Cargill dock, with none coming within 100 ft of the western channel edge. Two runs, by the same pilot, left the channel on the eastern side between the two docks. Examination of the track plots for repeat runs only (Plates 12-14) reveals that no vessels struck the fender system on Jordan Bridge for repeat tests. Inbound run track plots for all runs in the proposed 45-ft channel for Area B are shown in Plates 15-17. These plots also show the pilots having extreme difficulty passing through the Jordan Bridge. All runs stayed on the eastern side of the channel between Cargill dock and Amoco Oil dock as in the existing condition. One run, by the same pilot as before, left the eastern edge of the channel between the Amoco Oil dock and the Cargill dock, but not as much as with the existing channel. The pilot attributed the better run to having better control of the deeper draft vessel. The track plots of the repeat runs of the 40-ft draft ships (Plates 18-20) show that no vessels hit the fender on the Jordan Bridge and that no runs left the channel after passing through the bridge, although the run by the same pilot as before came within 20 ft of the channel edge. The pilot who had the problem leaving the channel near Cargill dock, although licensed for the Southern Branch of the Elizabeth River, is not as experienced in this area as the other pilots. Therefore, Area B2 plots of the other four pilots only are included as Plates 21 and 22.

Outbound runs. Track plots for outbound runs in the existing 40-ft channel for Area B are shown in Plates 23-25. These plots show a tendency to leave the channel by about 30 ft near Cargill dock. This occurred as pilots attempted to swing as far east as possible prior to entering the Jordan Bridge. At this point, none of the pilots used the western edge of the channel. None of the runs struck the fender system of either the Jordan Bridge or the Norfolk and Portsmouth Belt Line Bridge. Although several pilots got very close to the edge of the channel upstream of the floating dry dock, none of these runs left the channel. Track plots for the outbound runs of the proposed 45-ft channel are presented in Plates 26-28. These plots show test results very similar to those of the existing 40-ft channel. Pilots again left the defined channel on the east side near Cargill, and several pilots got close to the channel edge upstream of the floating dry dock. However, the pilots did not come as close to leaving the channel as they did for the existing condition. Also, the pilots did not use the western edge of the channel across from the Cargill dock.

Ship track plots, Area C

Composite piloted ship track plots for the six channel conditions tested in Area C are presented in Plates 29-38. A large-scale plot of both the Plan 1 and the Plan 2 turning basins has also been provided with these track plots. Each pilot was able to complete at least two runs of each test condition in Area C. Large-scale plots of both the Plan 1 and the Plan 2 turning basins are also provided for repeat runs only, to demonstrate the pilot's improvement from the first attempt at each turning basin.

Inbound runs. The composite track plot for existing condition inbound runs for Area C is shown in Plate 29. These track plots show a tendency of the pilots to cut too close to the channel's eastern edge, with some runs going out of the channel adjacent to the Tenneco dock. The track plots also show that the pilots cut too close to the western edge of the channel across from the Hess Oil barge dock. The pilots are forced into this tactic in an attempt to "straighten" the two bends, and not be out of position to make the final sharp turn prior to the Elizabeth River Terminals (ERT). Also, several of the pilots took the sharp turn too tightly and left the channel in front of the Blue Circle pier. One pilot, who was too far west when starting into the sharp turn, left the channel opposite the Blue Circle pier. Track plots of the Plan 1 channel runs (Plate 30) show that one pilot lost control of his ship near the McClean dock. The pilot stated that this was due to his error but he was able to regain control and complete the run. In general, the pilots were better able to control the deeper draft vessel, especially adjacent to the Tenneco dock and the Hess Oil barge dock. The track plots are also more consistent and tightly grouped in front of the Blue Circle pier. However, the pilots often left the channel there. Examination of the track plots for the Plan 2 channel (Plate 31) reveals runs similar to those of Plan 1, except that the pilots did utilize the widening near the Southern Block and Pipe dock.

Outbound runs. Track plots of Area C outbound runs in the existing 35-ft channel (Plate 32) show the pilots leaving the defined channel frequently while backing the vessel from ERT to the St. Julian Creek Turning Area and during the turning operation itself. After turning, the pilots stayed very close to the western channel edge across from the Hess Oil ship pier. Several of the pilots left the channel on the east side between the Southern Block and Pipe dock and the McClean dock in an attempt to line up for the Norfolk and Western Railway Bridge. Track plots of the runs of the Plan 1 channel (Plate 33) show that one pilot lost control of his ship across from the Southern Block and Pipe dock. The pilot stated that it was his error and the run was aborted prior to hitting the bridge. The track plot of all runs on the Plan 1 turning basin (Plate 34) shows several runs leaving the channel on the southern edge of the turning basin. Examination of the track plot for repeat runs only (Plate 35) reveals that for repeat runs, only one pilot left the channel on the southern edge of the basin. It should be noted that had the pilot been further east he would have stayed within the turning basin. Vessels leaving the channel on the north side of the basin near ERT did not present a problem since they were moving into an area they had just occupied while they were docked. However, those vessels leaving the northern edge of the basin near ERT II could present a problem to vessels docked there. The closest any vessel came to ERT II was about 70 ft. Once the turn was completed, because of the sharp turn at St. Julian Creek, the pilots used the deeper terminal approach channel on the north side between ERT and the Blue Circle pier. Therefore, the ships went too far to the west when passing the St. Julian Creek Turning Area and the Hess Oil ship terminal. The other problem area was adjacent to the Southern Block and Pipe dock. Here, as in the existing channel, the pilots swung east of the channel limits in an attempt to line up for the Norfolk and Western Railway Bridge. Track plots for the Plan 2 channel (Plate 36) show runs

similar to those of Plan 1, after the vessel had been turned. However, the pilots did take advantage of the widening near the Southern Block and Pipe dock. This widening helped the pilots line up their vessels in approaching the bridge. Track plots of all turning basin runs for Plan 2 (Plate 37) show more runs staying within the southern boundary of the turning basin than for Plan 1. However, it should be noted that those runs that left the basin on the north side came dangerously close to ERT II. One run came as close as 8 ft to the dock and four other runs came within 25 ft of the dock. Examination of the plots for repeat runs only (Plate 38) show little improvement for repeat runs of the Plan 2 turning basin. Turns done in the Plan 2 basin took an average of approximately 5 min longer than those in the Plan 1 basin. This is because the vessels first had to move east to use the basin.

Statistical Analysis

During each run, the control, positioning, and orientation parameters of the ship were recorded every 5 sec. These parameters included position, speed, rpm of the propeller, rudder angle, rate of turn, heading, drift angle, and port and starboard clearances. An additional parameter, the maneuvering factor, is calculated as the rpm multiplied by the rudder angle. Since five licensed pilots participated in the study, making at least two runs each for every condition, it was decided that statistical analysis could be based on parameter means rather than concentrating on individual runs.

All statistical parameters are plotted against distance along track. The distance along track is calculated by projecting the position of the ship center of gravity perpendicular to the center line of the channel and is measured from the beginning of the center line. For this study, plots of the center line as well as the distance from the beginning of the center line are shown in Figures 17-19.

For all parameters except clearance, the statistical analysis is presented as a mean of means within a sample channel section. A 500-ft channel section was used. Therefore, for each individual run, each parameter was averaged over 500 ft, and then these means were averaged over all runs under a given condition, thus a mean of the means. The standard deviation of the means was calculated for each run, and these standard deviations were averaged over all runs under a given condition.

Statistical analysis of clearance is presented as a mean of the minimum during a sample channel section, which means that the minimum clearance for port and starboard is found for each channel section of each run. These minimums are then averaged over all runs for each test condition.

Area A

Minimum port clearance. Examination of the port clearance plot

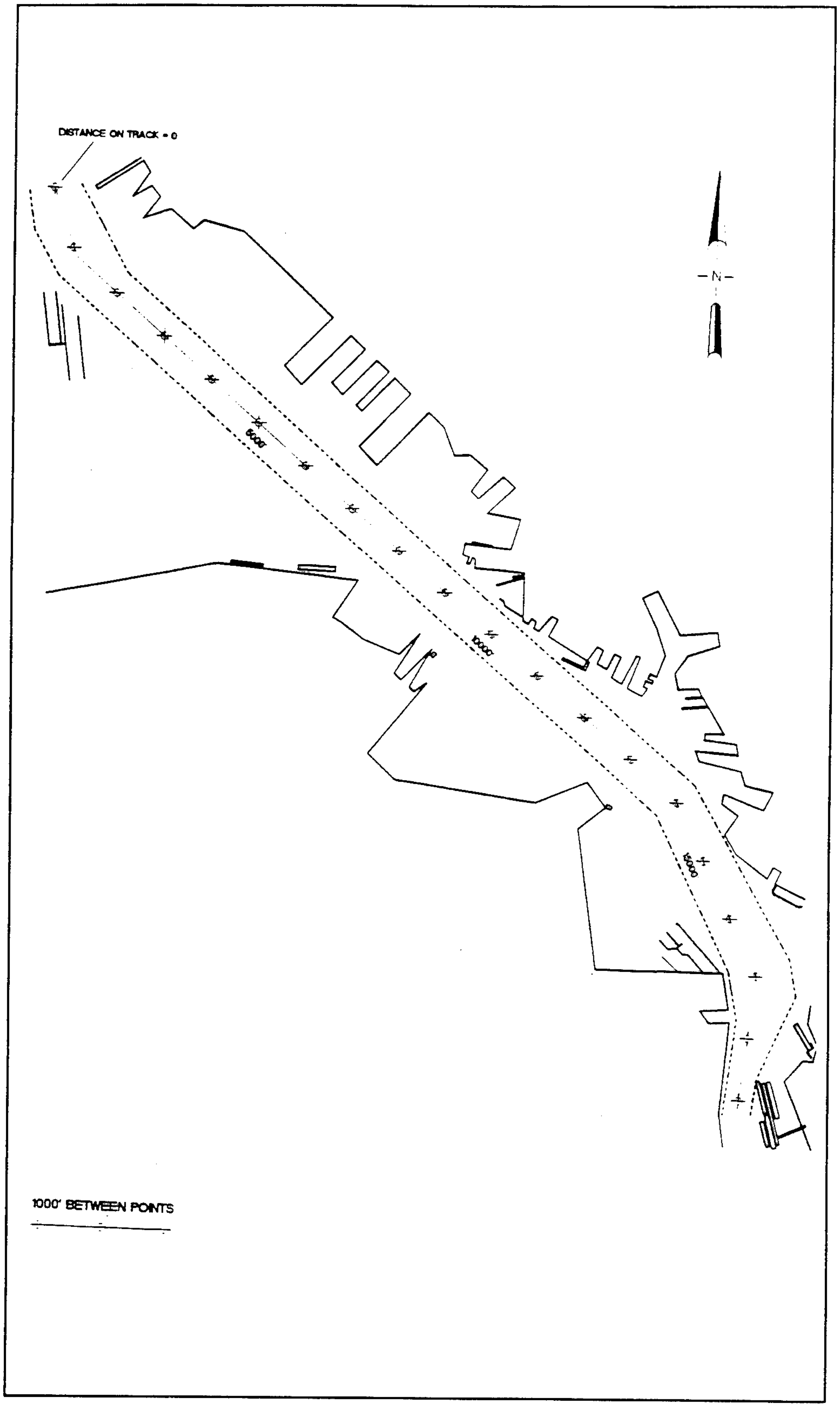


Figure 17. Distance along track, Area A

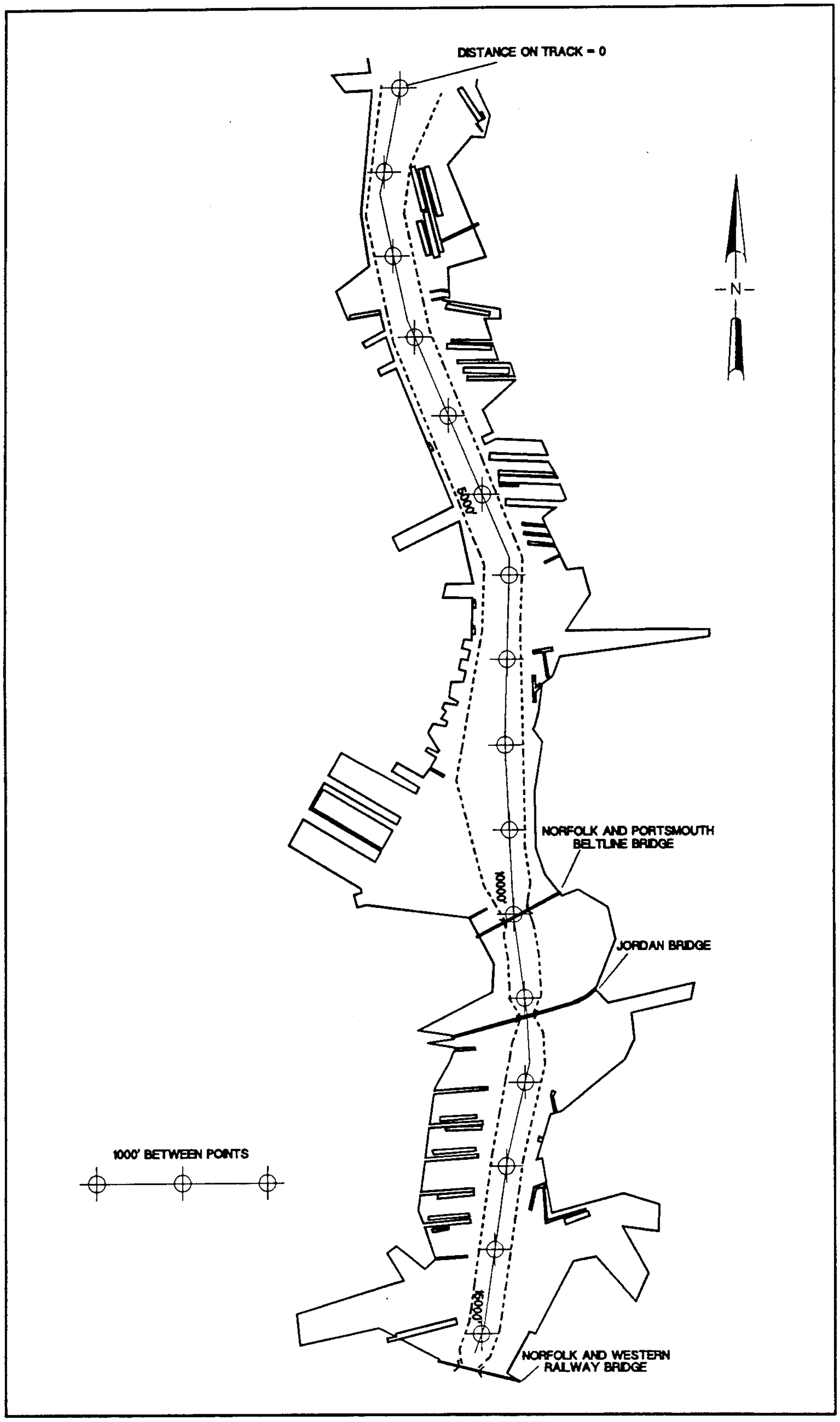


Figure 18. Distance along track, Area B

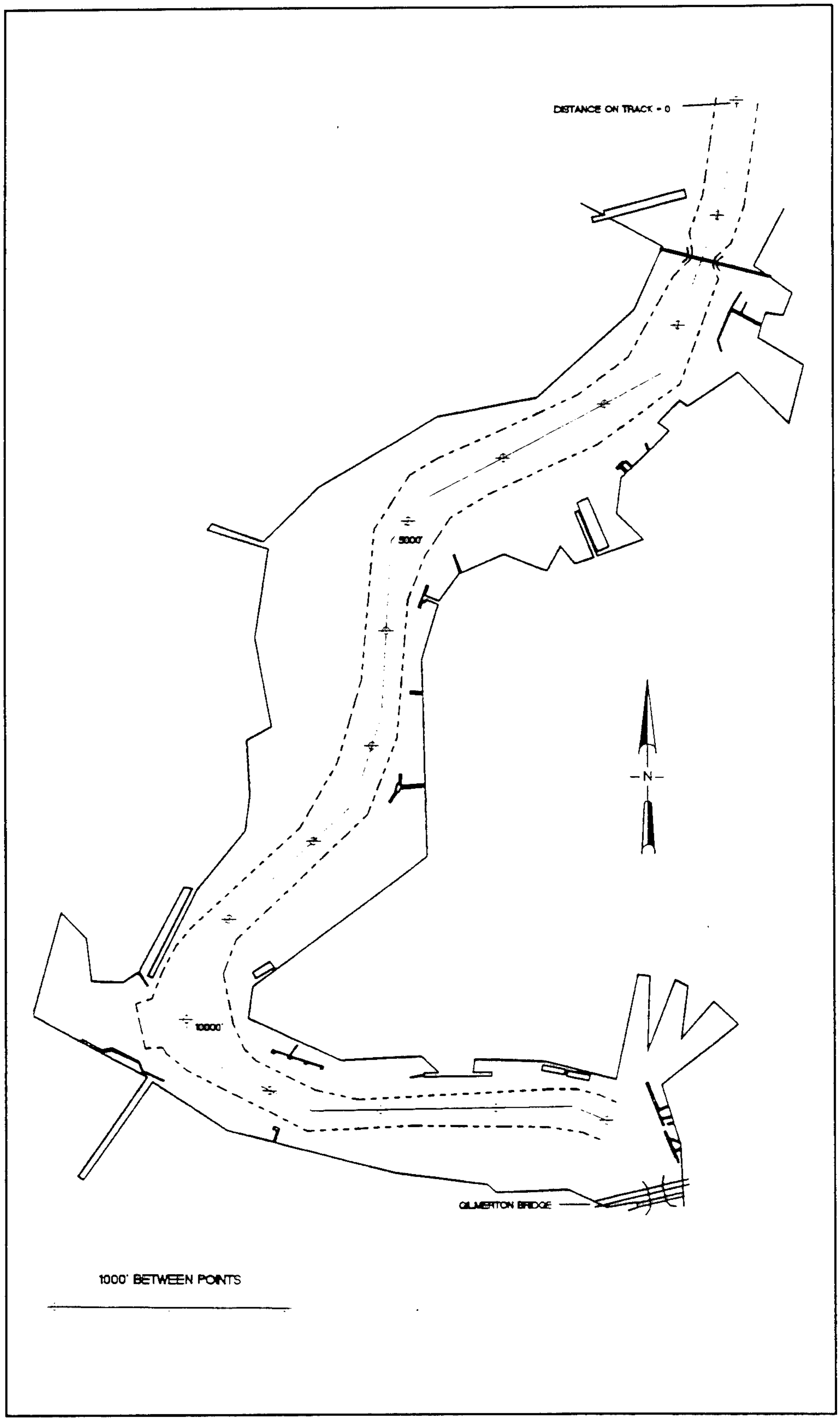


Figure 19. Distance along track, Area C

(Plate 39) reveals no significant difference in the mean minimum port clearances of the existing 40-ft channel and the proposed 45-ft channel, for either inbound or outbound runs.

Minimum starboard clearance. The plot of the starboard clearance (Plate 40) shows that the mean minimum starboard clearance for both existing and proposed channels is very similar and allows for clearance for runs going both inbound and outbound.

Rudder angle, rpm, speed, and maneuvering factor. The plot of the mean rudder angle (Plate 41) shows that the pilots used approximately the same rudder commands for runs in either channel, both inbound and outbound. Neither channel condition required the maximum rudder available. The plots of the rpm and speed (Plates 42 and 43, respectively) show that the pilots tended to run the 45-ft-draft vessel faster on the inbound runs and the 40-ft-draft ship faster on the outbound runs. For the most part, the difference in speed is 1 knot or less. Plots of the maneuvering factor (Plate 44) show the same trends as the rudder angle plot. Neither draft vessel used more than 60 percent of the maneuvering available.

Drift angle. Examination of the drift angle (Plate 45) shows that after the first 2,000 ft of the run, the mean drift angle is nearly identical for both draft ships, inbound and outbound.

Area B

Minimum port clearance. Examination of the mean minimum port clearance (Plate 46) shows negative values for both draft ships as the vessels passed through the Jordan Bridge on inbound runs. A plot of the mean minimum port clearance is included for repeat runs only (Plate 47). It shows that the pilots were able to keep the vessels from striking the port fender of the Jordan Bridge on repeat runs. However, the pilots were able to keep the 40-ft-draft ships 30 ft from the bridge fender, while the 45-ft-draft ships came within 10 ft. Plates 46 and 47 show little difference in mean minimum port clearances for outbound runs.

Minimum starboard clearance. The plot of the starboard clearance (Plate 48) shows that the mean minimum starboard clearances for both existing and proposed channels are very similar and allow adequate clearance through the Jordan Bridge. However, it should be noted that these plots include the runs that struck the port fender of the Jordan Bridge. The inclusion of these runs will exaggerate the amount of starboard clearance. The plot of repeat runs only (Plate 49) shows that there is less starboard clearance through the Jordan Bridge when only runs that did not hit the port fender are plotted. The mean minimum starboard clearance for the existing condition was nearly 0 ft as the ship passed between the fenders.

Rudder angle, rpm, speed, and maneuvering factor. The plot of the mean rudder angle (Plate 50) shows the same trends in the mean rudder angle for runs in either channel, both inbound and outbound. Neither channel condition required the maximum rudder available. The plots of the rpm and speed (Plates 51 and 52, respectively) show that the pilots used more engine speed for the 40-ft-draft vessel through the bridges on inbound runs. Also, the pilots drove the 45-ft-draft ship faster on the final 5,000 ft of the outbound runs. Plots of the maneuvering factor (Plate 53) show that the different draft vessels required nearly the same amount of maneuvering for both inbound and outbound runs. Neither draft vessel used *nearly* all the maneuverability available.

Drift angle. Examination of the drift angle plot (Plate 54) shows that the mean drift angle is nearly identical for both draft ships, inbound and outbound.

Area C

Minimum port clearance. Examination of the mean minimum port clearance plot for Area C (Plate 55) shows a grounding area between Swann Oil pier and ERT II. Runs for both Plans 1 and 2 as well as existing conditions grounded in this area. The worst case was Plan 1. However, it should be noted that for inbound runs in this area, Plan 1 and Plan 2 should be identical. The outbound runs show groundings for the existing channel as the vessel turned in the St. Julian Creek Turning Area. Once turned, the plots show adequate clearance for existing conditions. The plots of mean minimum port clearance for the plans show no groundings, but the clearance for Plan 2 gets very small near the St. Julian Creek Turning Area.

Minimum starboard clearance. Examination of the mean minimum starboard clearance plot for Area C (Plate 56) shows adequate starboard clearance for all three plans during inbound runs. The outbound runs show groundings for the existing channel as the vessel turned in the St. Julian Creek Turning Area. Once turned, the plots show adequate clearance for all plans.

Rudder angle. The plot of the mean rudder angle (Plate 57) shows the same trends in the mean rudder angle for inbound runs in all three channels. The deeper draft vessels of Plans 1 and 2 required more rudder at the peaks near distance 4,500 ft and near the St. Julian Creek Turning Area. The lighter ship required more rudder near the Hess Oil barge dock. For outbound runs, the pilots operated the rudder of the existing 35-ft-draft ships differently from the 40-ft-draft ships. Pilots maneuvered the ships from the port side of the channel at Hess Oil ship dock to the starboard side of the channel just north of the Tenneco dock and then swung hard back to port to pass through the Norfolk and Western Railway Bridge. Therefore, the plot of the mean rudder angle for outbound runs shows more rudder action for the existing channel. This is consistent with the track plots (Plate 32) for the existing channel, and the pilots' statements that the deeper draft ship was more controllable. The plot of the outbound runs also shows that the pilots utilized the widener in

Plan 2 by waiting until later to turn the ship to port, thus having a straighter line to the bridge.

Rpm and speed. The plots of the rpm and speed (Plates 58 and 59, respectively) show that pilots handled the vessels in all three channels almost identically for inbound runs. For outbound runs, the pilots gave the 35-ft vessels more rpm after the St. Julian Creek Turning Area than they did for the 40-ft-draft ships. The pilots did not give the 40-ft-draft ships as much rpm in this area because for Plans 1 and 2, they were headed forward through the sharp turn at the St. Julian Creek and were operating mainly by tugs. The pilots cut the rpm for the deeper draft ships just past the Tenneco Dock, but did not cut the rpm for the 35-ft-draft ship.

Maneuvering factor. Plots of the maneuvering factor (Plate 60) show that different draft vessels required nearly the same amount of maneuvering for the inbound runs. For outbound runs, the ships operating in the existing channel required about twice the maneuvering of the 40-ft-draft ships.

Drift angle. Examination of the drift angle (Plate 61) shows that the mean drift angle is almost identical for both draft ships for inbound transits only. The drift angles are shown for the outbound runs only after the vessels passed the Hess Oil barge dock. Prior to this point, the turning maneuvers rendered the drift angle invalid as a useful parameter. The drift angle for the existing condition lagged behind the two plans because of the different methods of transiting the reach.

5 Recommendations

Existing 40-ft Channel

Based on the pilots' simulation track-line plots, the pilots' test run ratings, and the pilots' final questionnaires, it is determined that deepening the existing channel 5 ft, from 40 ft to 45 ft, will not impose a safety hazard on vessels transiting the reach from Lamberts Point to the Norfolk and Western Railway Bridge. The main area of concern in this reach is passing through the Norfolk and Portsmouth Belt Line Bridge and the Jordan Bridge. Simulation runs showed that the pilots have a difficult time navigating this area, especially on inbound runs. However, the runs did improve considerably after the pilots became more familiar with the simulator. There is ample room for passing in the reach between Lamberts Point and the Elizabeth River Eastern Branch.

Simulation tests revealed channel realignment as a possible option for the reach between the Jordan Bridge and the Norfolk and Western Railway Bridge. Since the pilots kept their vessels on the eastern edge of the channel through this area for either inbound or outbound runs, and did not use the western edge for through transits, it is proposed that the channel be realigned (Figure 20) to accommodate the pilots' natural path through this reach.

Existing 35-ft Channel

Based on the pilots' simulation track plots, the pilots' test run ratings, and the pilots' final questionnaires, it is recommended that some widening of the channel be done in this reach. Figure 21 illustrates the recommended areas of widening. Both widenings designed by the Norfolk District and tested in the simulator will be beneficial for navigation in this reach. It is also recommended that the channel be widened on the west side by 50 ft between the Hess Oil ship dock and the Tenneco dock. This widening should flair out north of the St. Julian Creek area to a maximum widening of 165 ft, which will allow safe navigation for outbound vessels that have been turned in the turning basin and are traveling forward through this area and will allow inbound vessels safer navigation of the turn near St. Julian Creek. It is also recommended that the channel be straightened on the north side between Blue Circle and ERT.

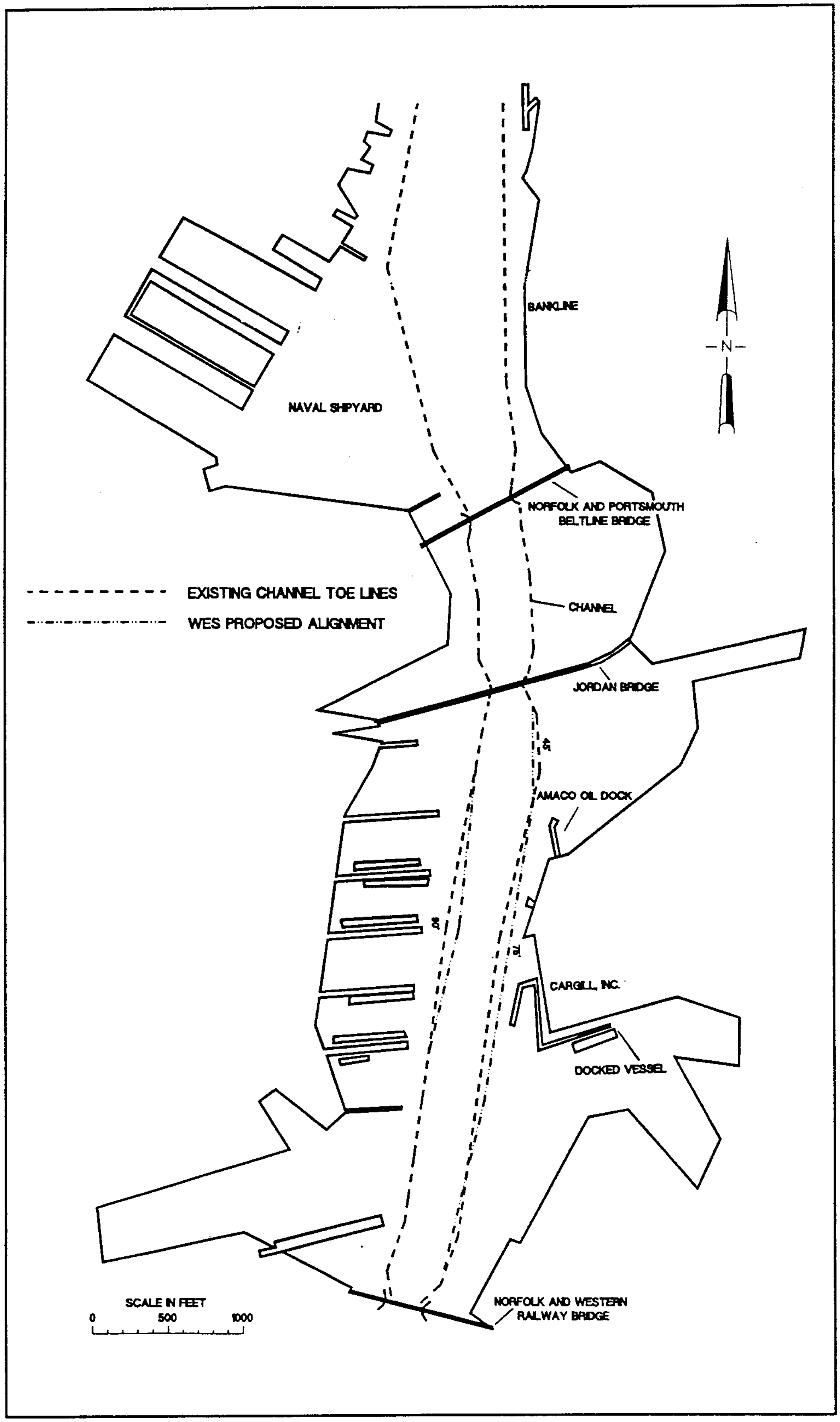


Figure 20. Recommended channel, Area B

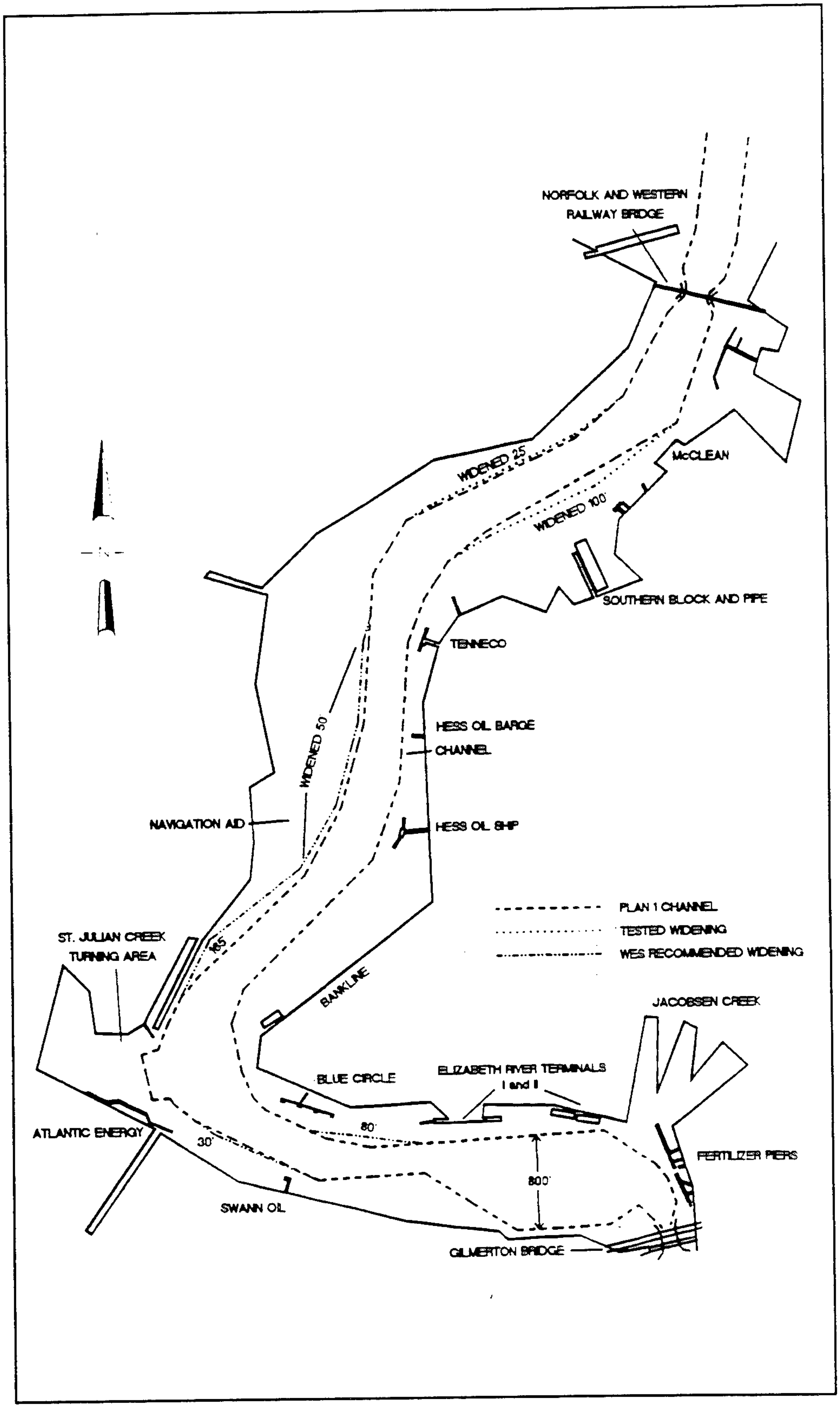


Figure 21. Recommended channel, Area C

In this case, the channel should be widened by 80 ft at the farthest point, which will aid both inbound and outbound runs. It is also recommended that the channel be widened by 30 ft between the Swann Oil terminal and the Atlantic Energy dock, which will help provide a safe transit for inbound vessels making the sharp turn prior to ERT.

Turning Basin

Based on the pilots' simulation track-line plots, the pilots' test run ratings, and the pilots' final questionnaires, it is recommended that the Plan 1 turning basin be built. This plan was the unanimous choice of the pilots tested. Vessels turning in the Plan 2 basin come dangerously close to the ERT II.

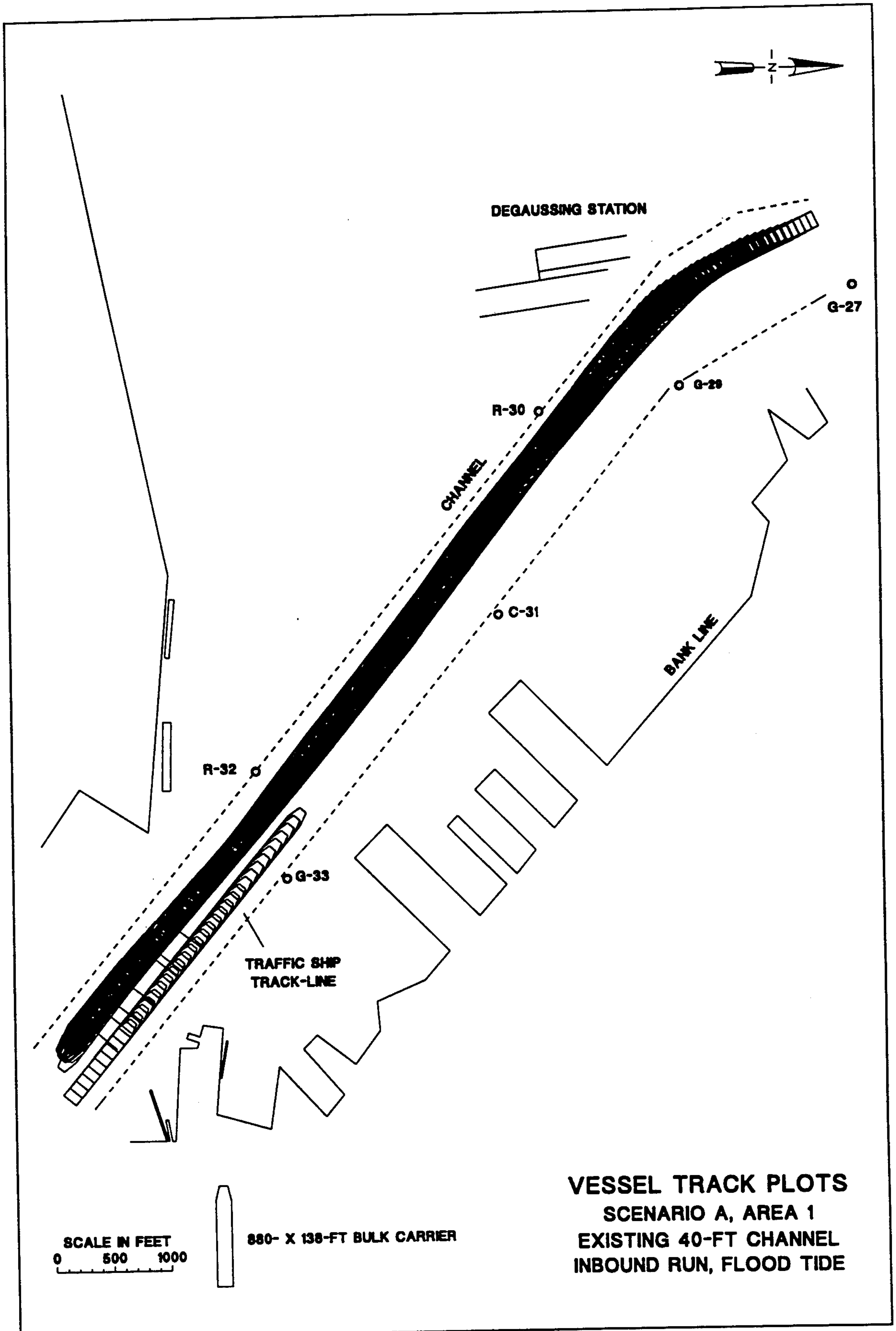
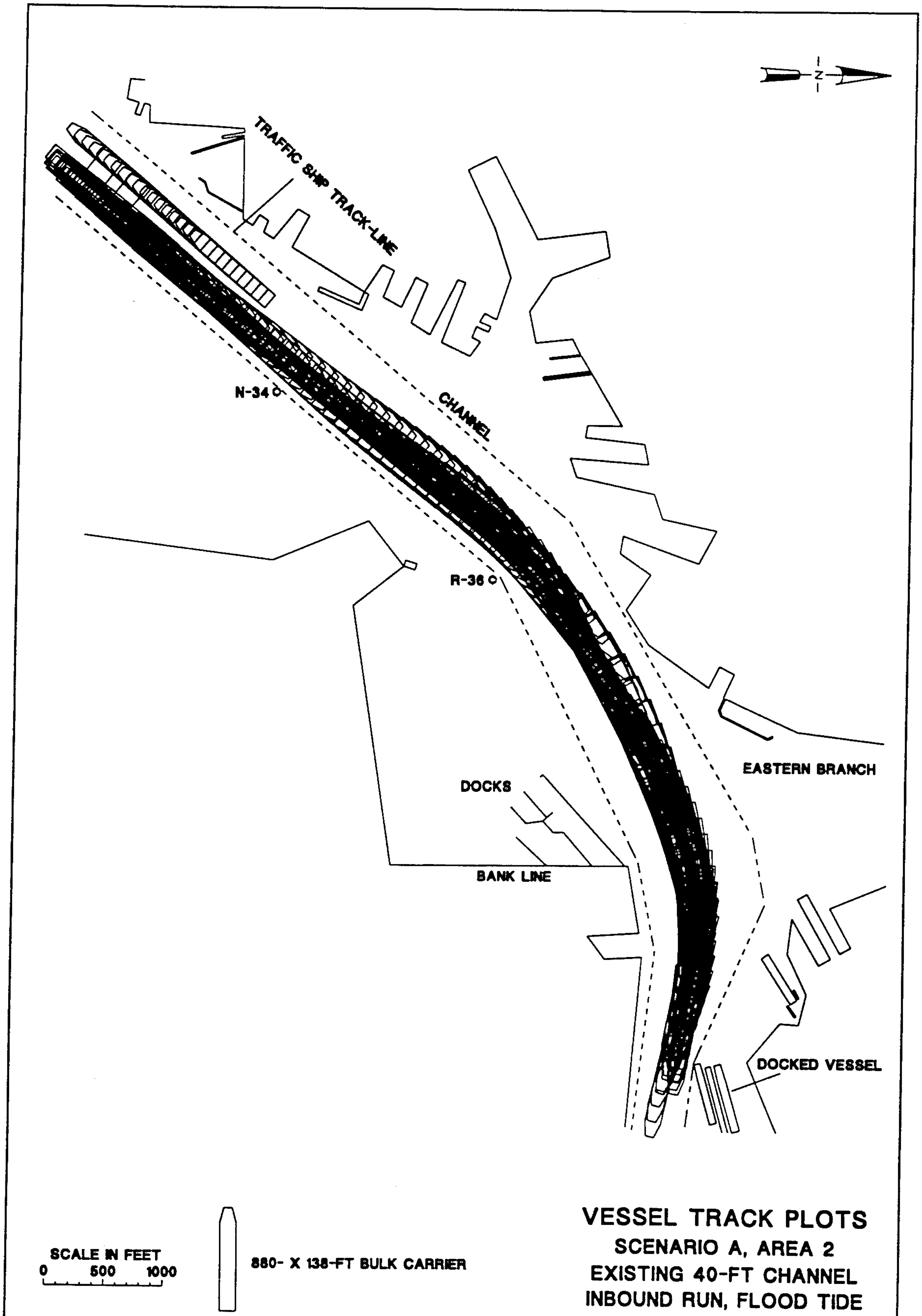
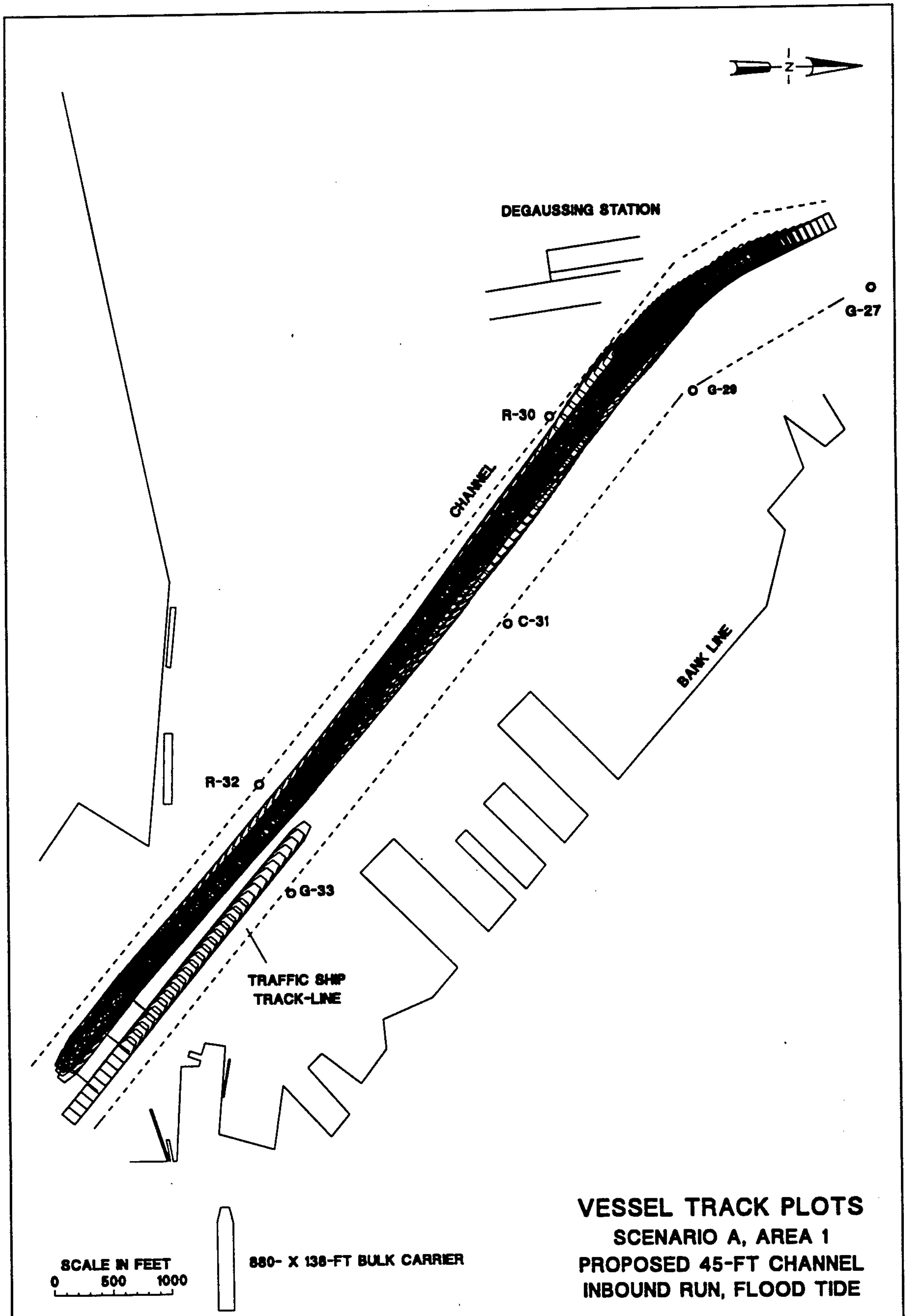

N
DEGAUSSING STATION
G-27
G-29
R-30
CHANNEL
C-31
BANK LINE
R-32
G-33
TRAFFIC SHIP
TRACK-LINE
SCALE IN FEET
0 500 1000
880- X 138-FT BULK CARRIER
VESSEL TRACK PLOTS
SCENARIO A, AREA 1
EXISTING 40-FT CHANNEL
INBOUND RUN, FLOOD TIDE

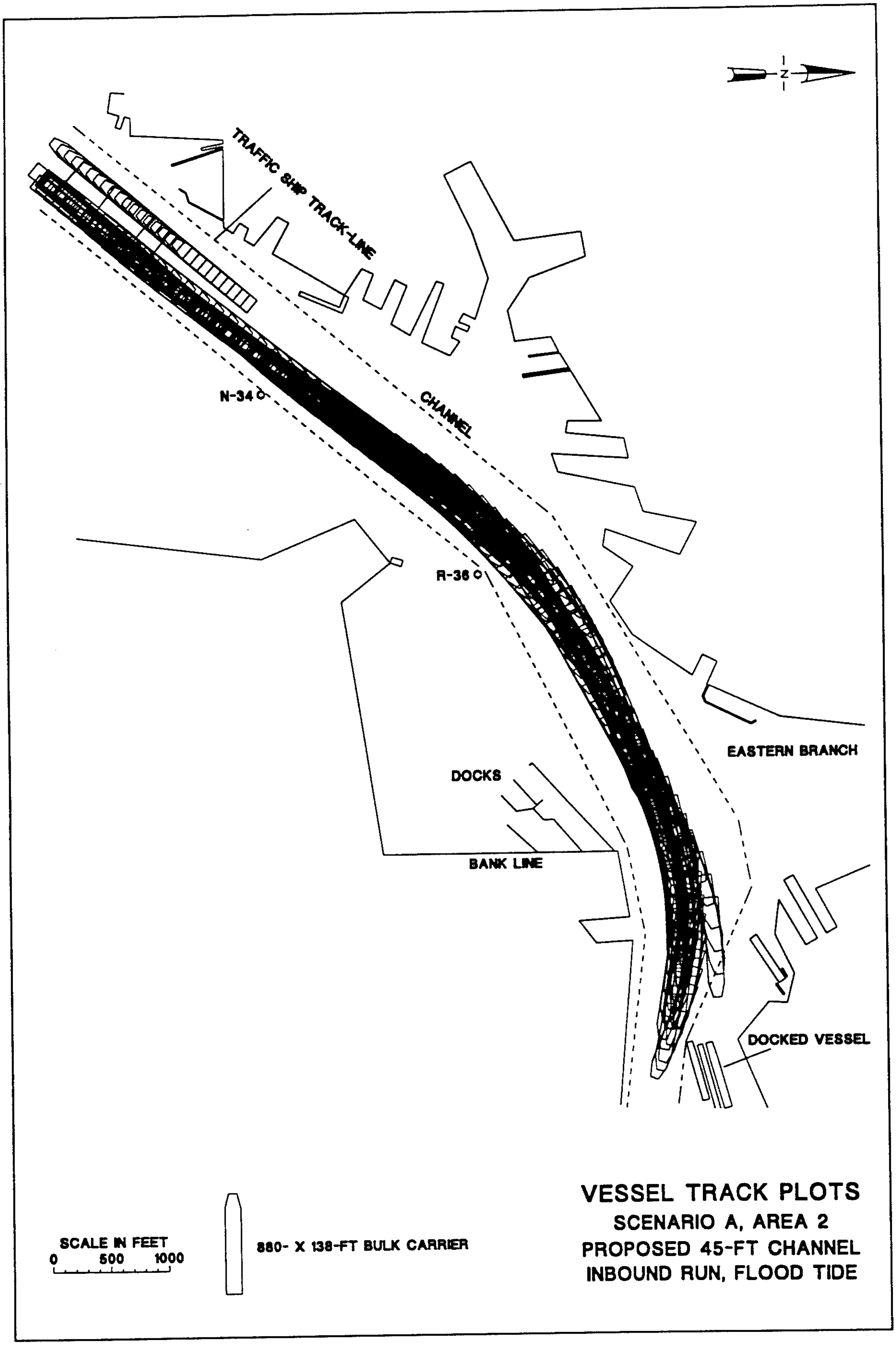
Plate 1



VESSEL TRACK PLOTS
SCENARIO A, AREA 2
EXISTING 40-FT CHANNEL
INBOUND RUN, FLOOD TIDE

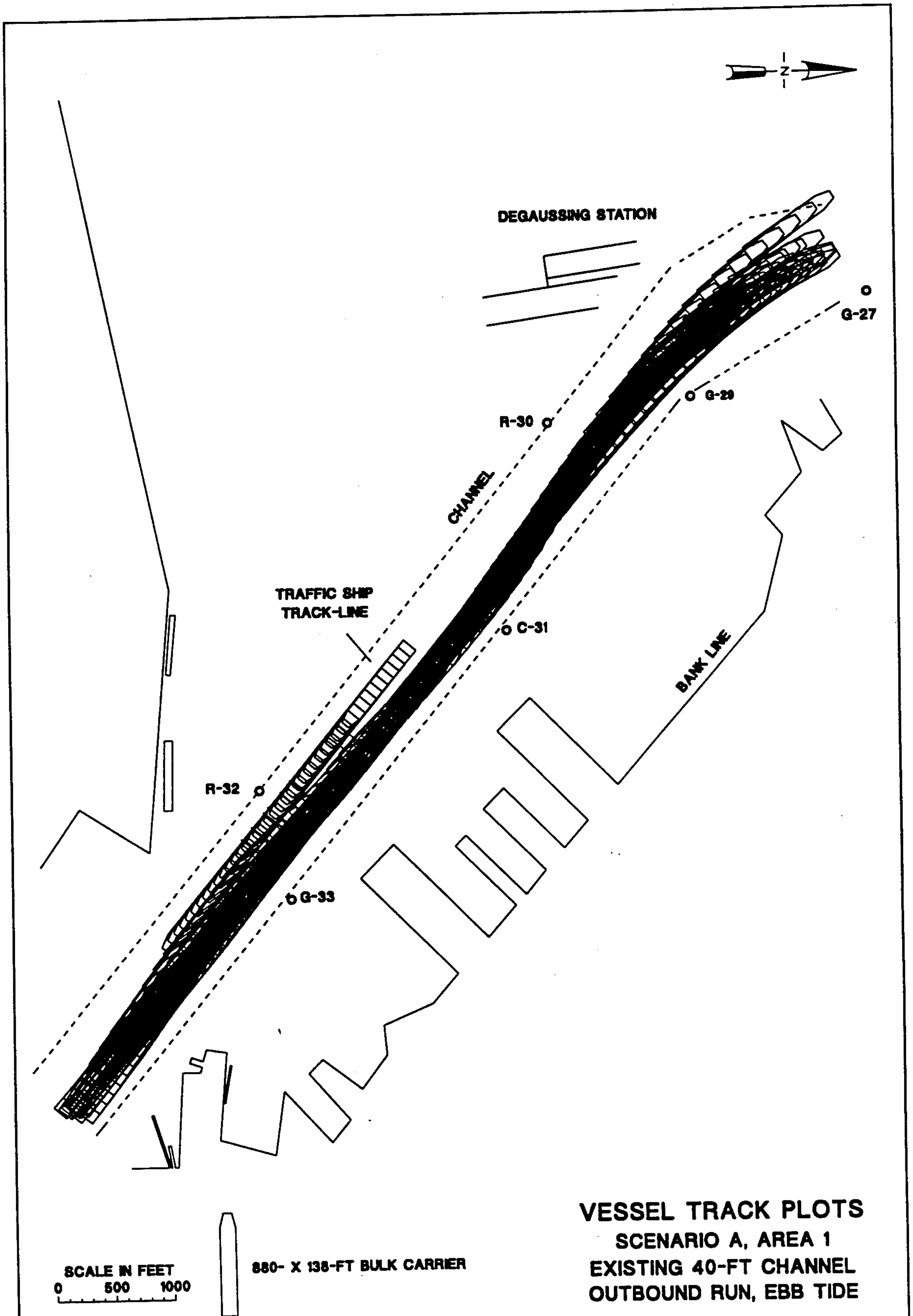


VESSEL TRACK PLOTS
SCENARIO A, AREA 1
PROPOSED 45-FT CHANNEL
INBOUND RUN, FLOOD TIDE



VESSEL TRACK PLOTS
SCENARIO A, AREA 2
PROPOSED 45-FT CHANNEL
INBOUND RUN, FLOOD TIDE

Plate 4



VESSEL TRACK PLOTS
SCENARIO A, AREA 1
EXISTING 40-FT CHANNEL
OUTBOUND RUN, EBB TIDE

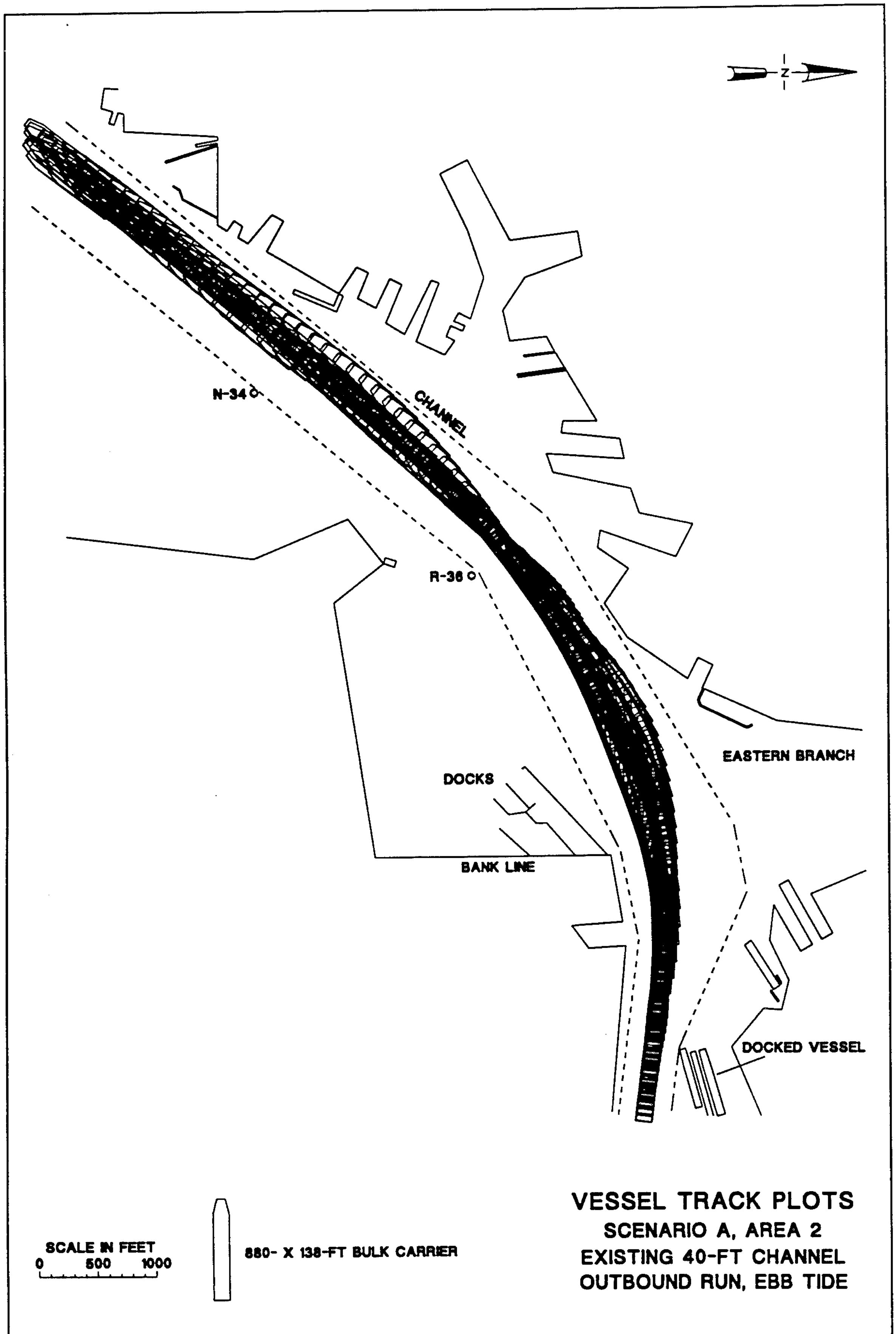
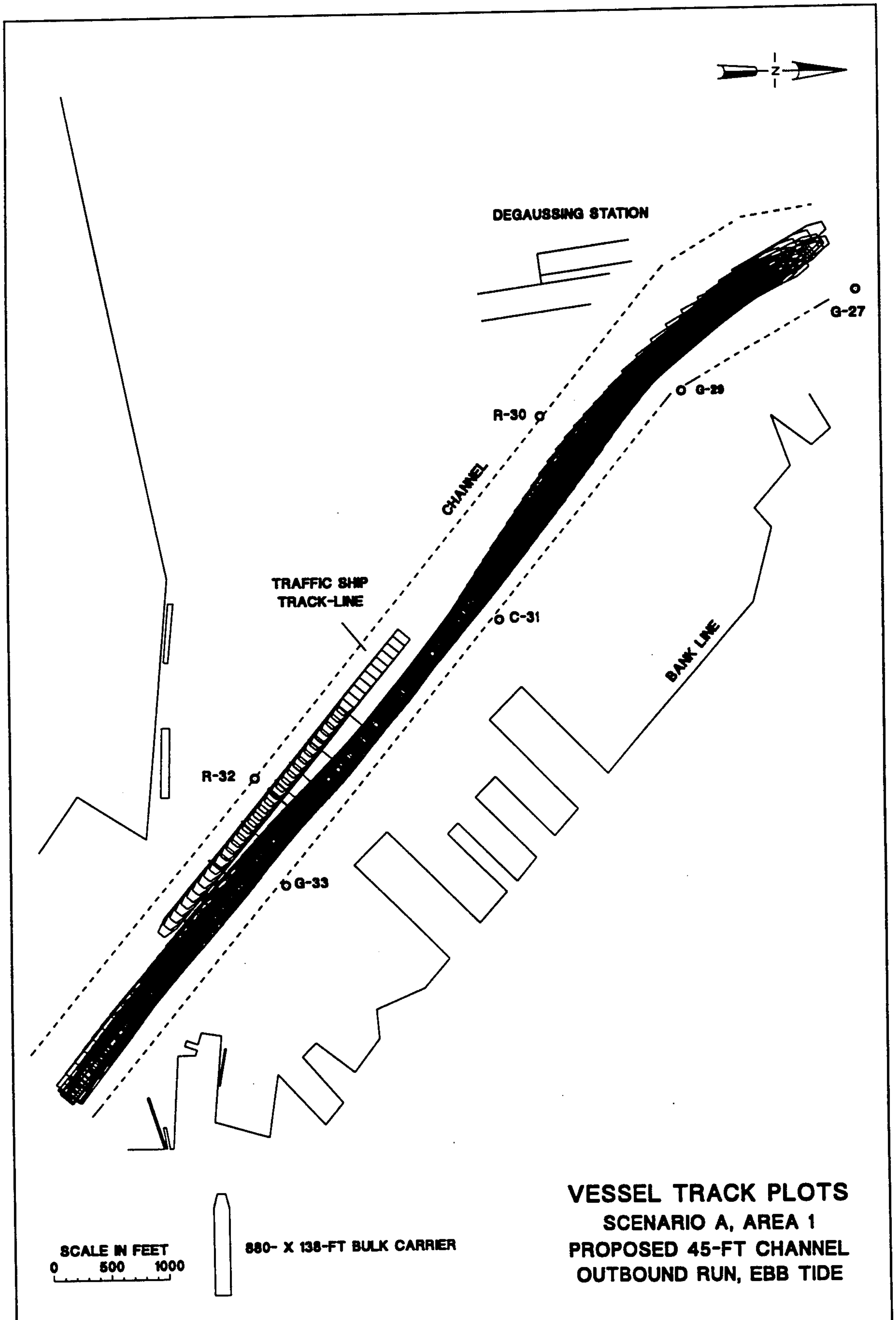

N
CHANNEL
N-34
R-36
EASTERN BRANCH
DOCKS
BANK LINE
DOCKED VESSEL
VESSEL TRACK PLOTS
SCENARIO A, AREA 2
EXISTING 40-FT CHANNEL
OUTBOUND RUN, EBB TIDE
SCALE IN FEET
0 500 1000
880- X 138-FT BULK CARRIER

Plate 6



VESSEL TRACK PLOTS
SCENARIO A, AREA 1
PROPOSED 45-FT CHANNEL
OUTBOUND RUN, EBB TIDE

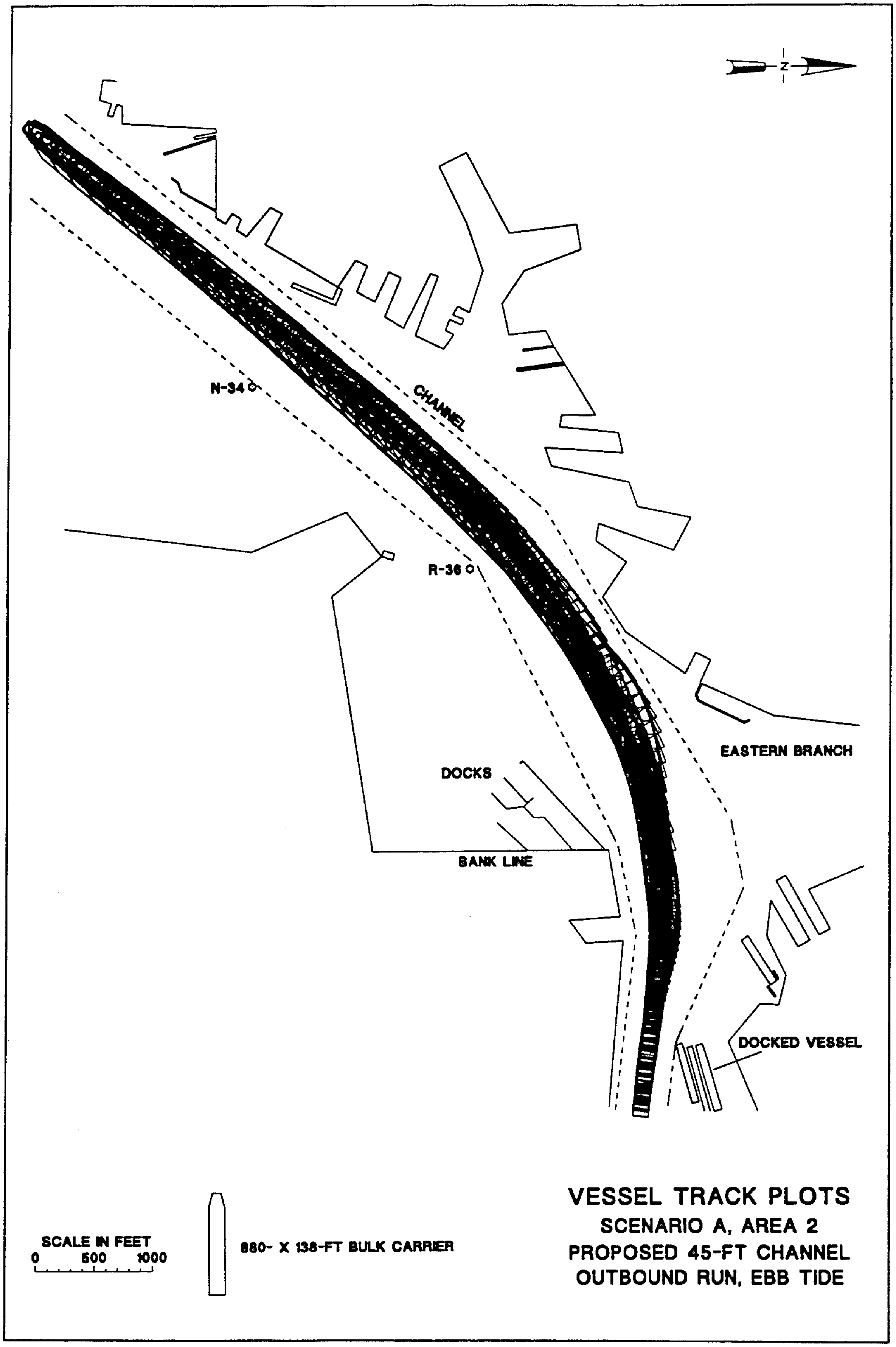

N
CHANNEL
N-34
R-36
EASTERN BRANCH
DOCKS
BANK LINE
DOCKED VESSEL
SCALE IN FEET
0 500 1000
880- X 138-FT BULK CARRIER
VESSEL TRACK PLOTS
SCENARIO A, AREA 2
PROPOSED 45-FT CHANNEL
OUTBOUND RUN, EBB TIDE

Plate 8

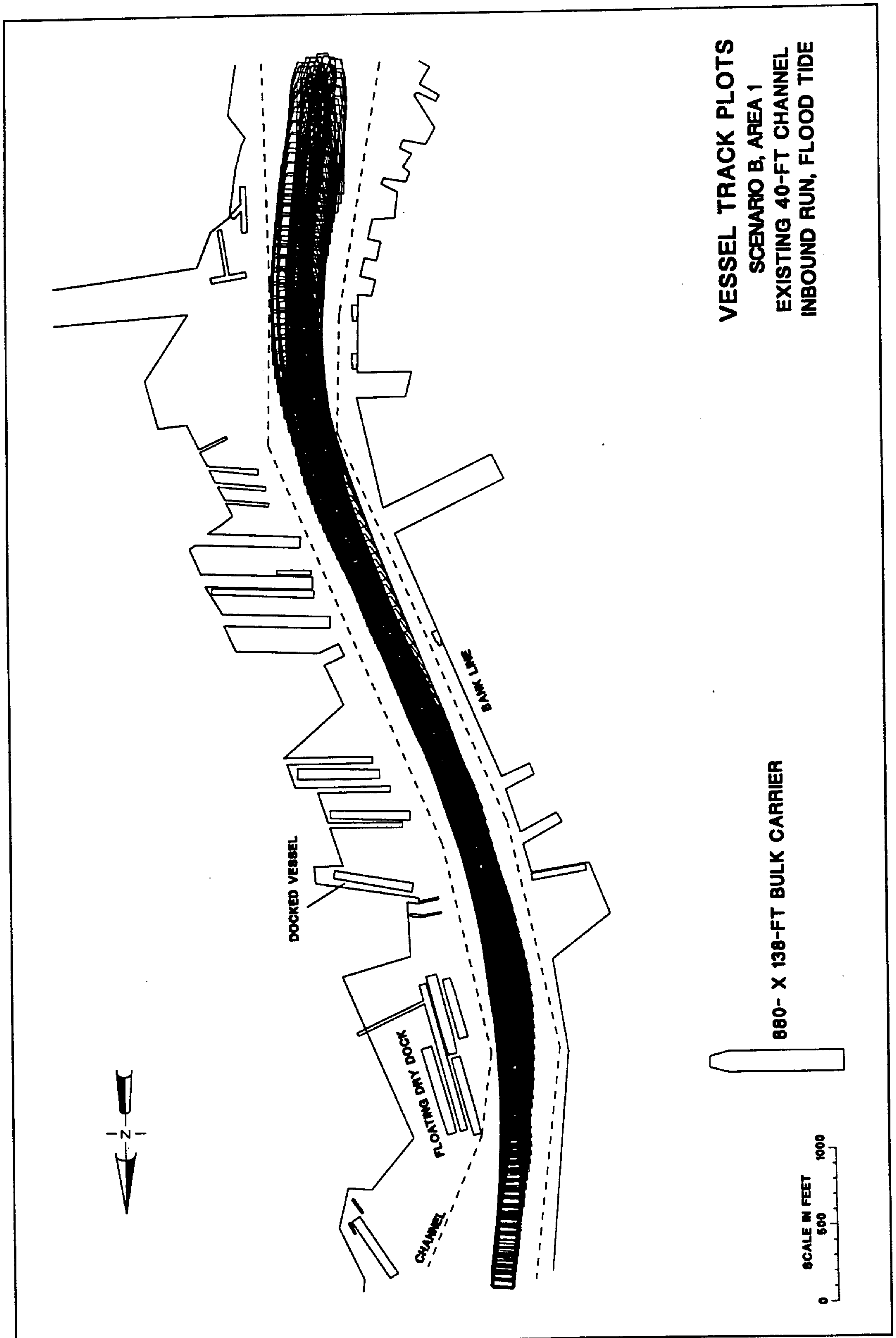

VESSEL TRACK PLOTS
SCENARIO B, AREA 1
EXISTING 40-FT CHANNEL
INBOUND RUN, FLOOD TIDE
880- X 138-FT BULK CARRIER
BANK LINE
DOCKED VESSEL
FLOATING DRY DOCK
CHANNEL
N
SCALE IN FEET
0
500
1000

Plate 9

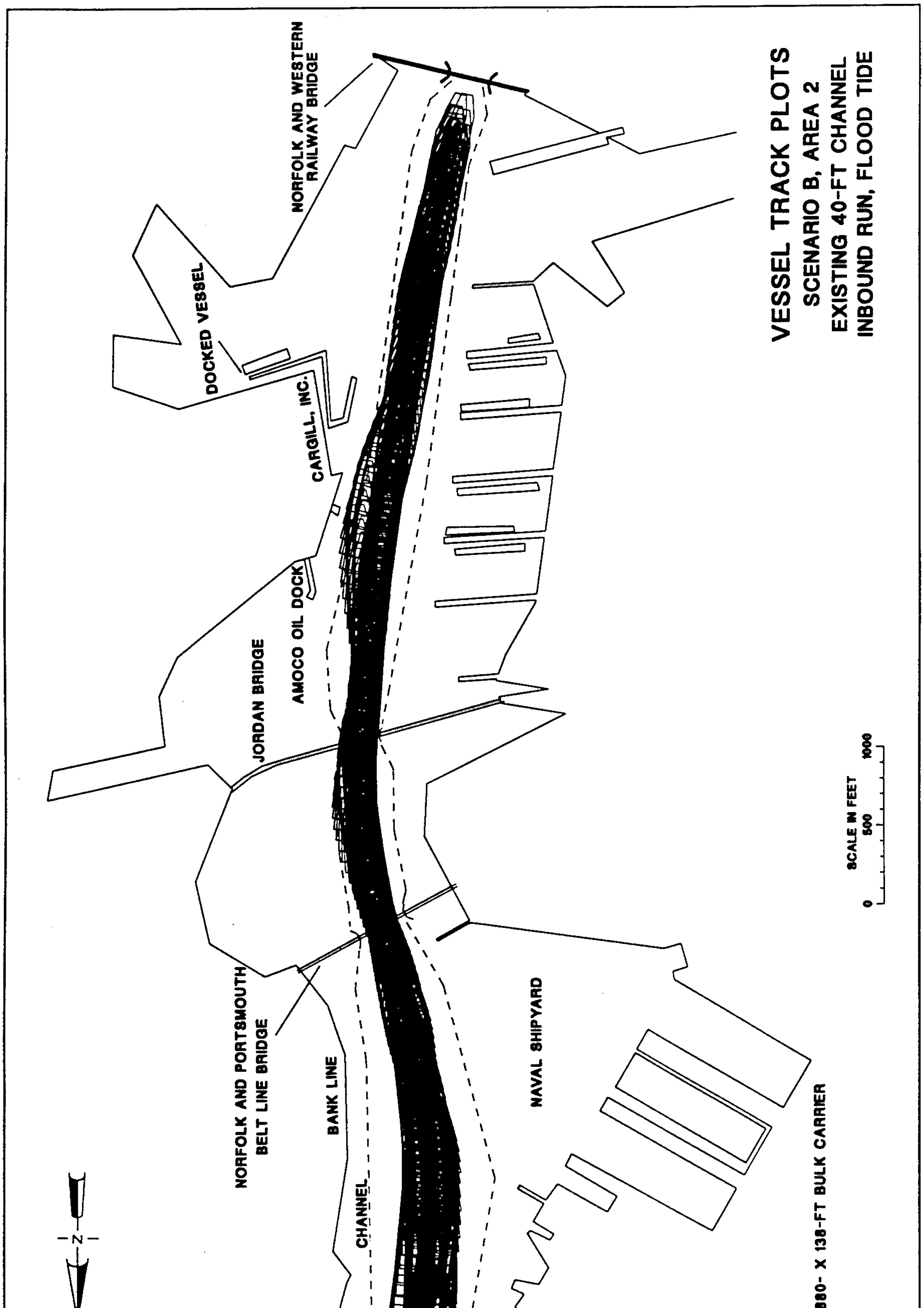
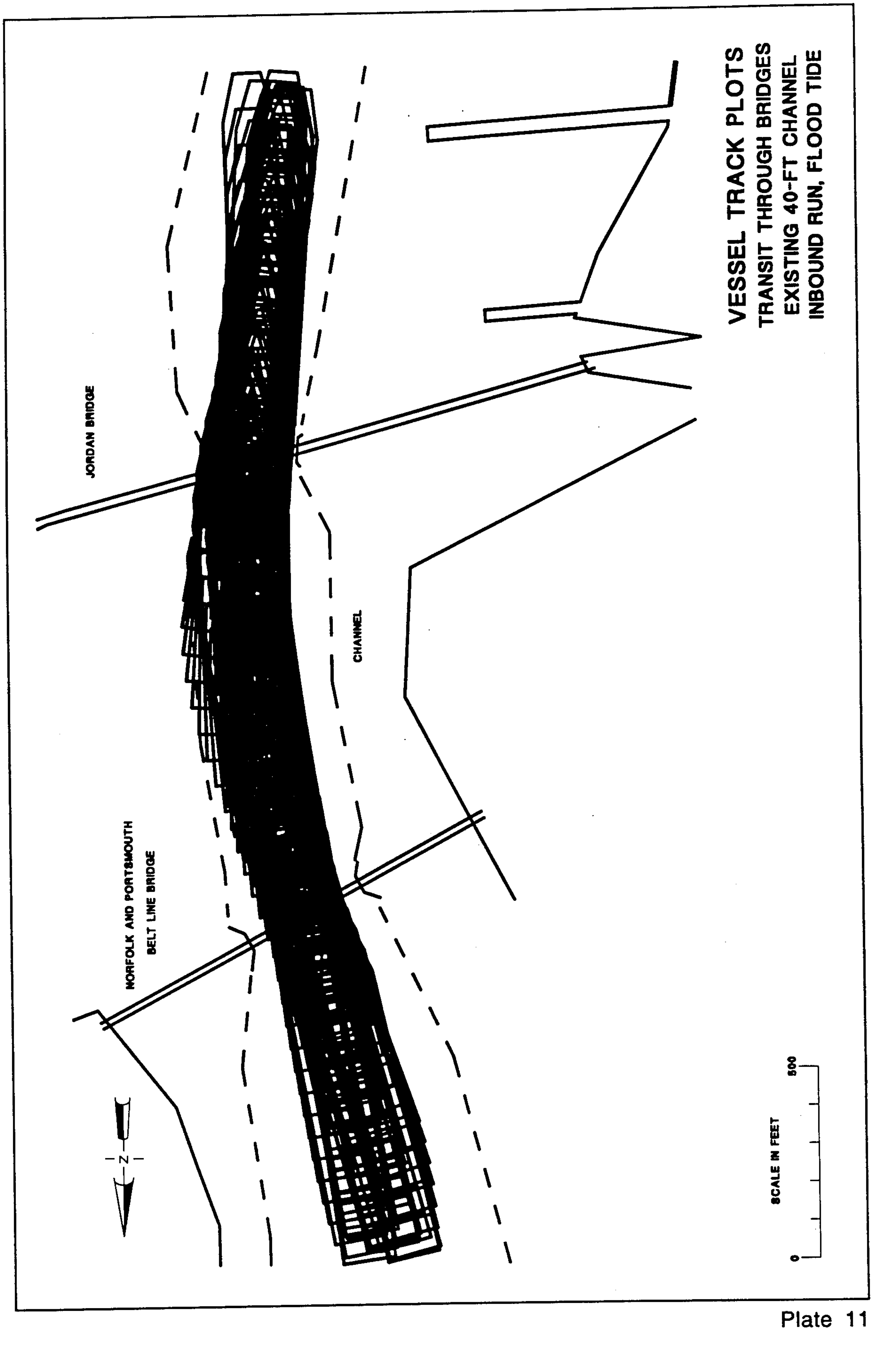
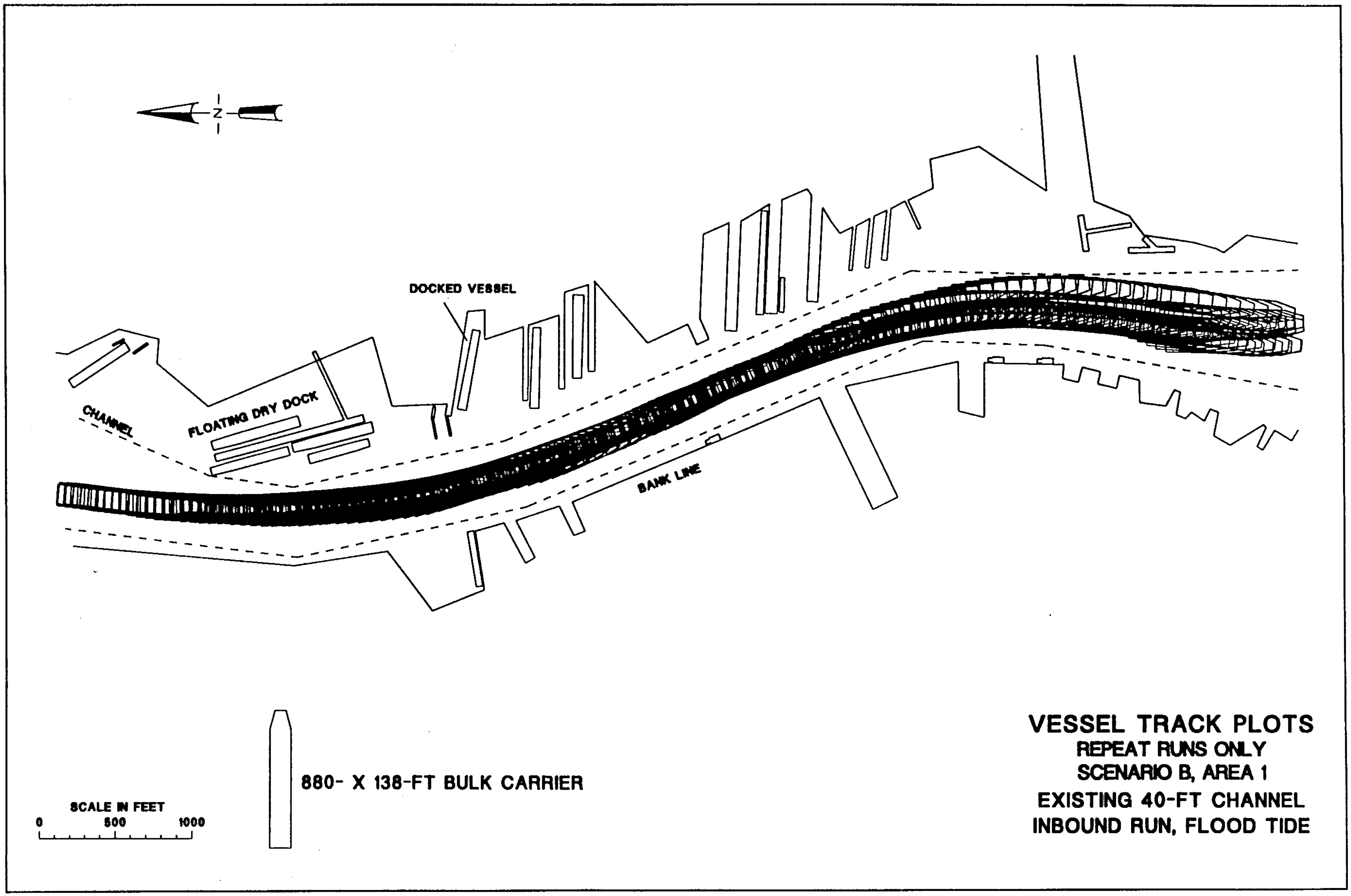
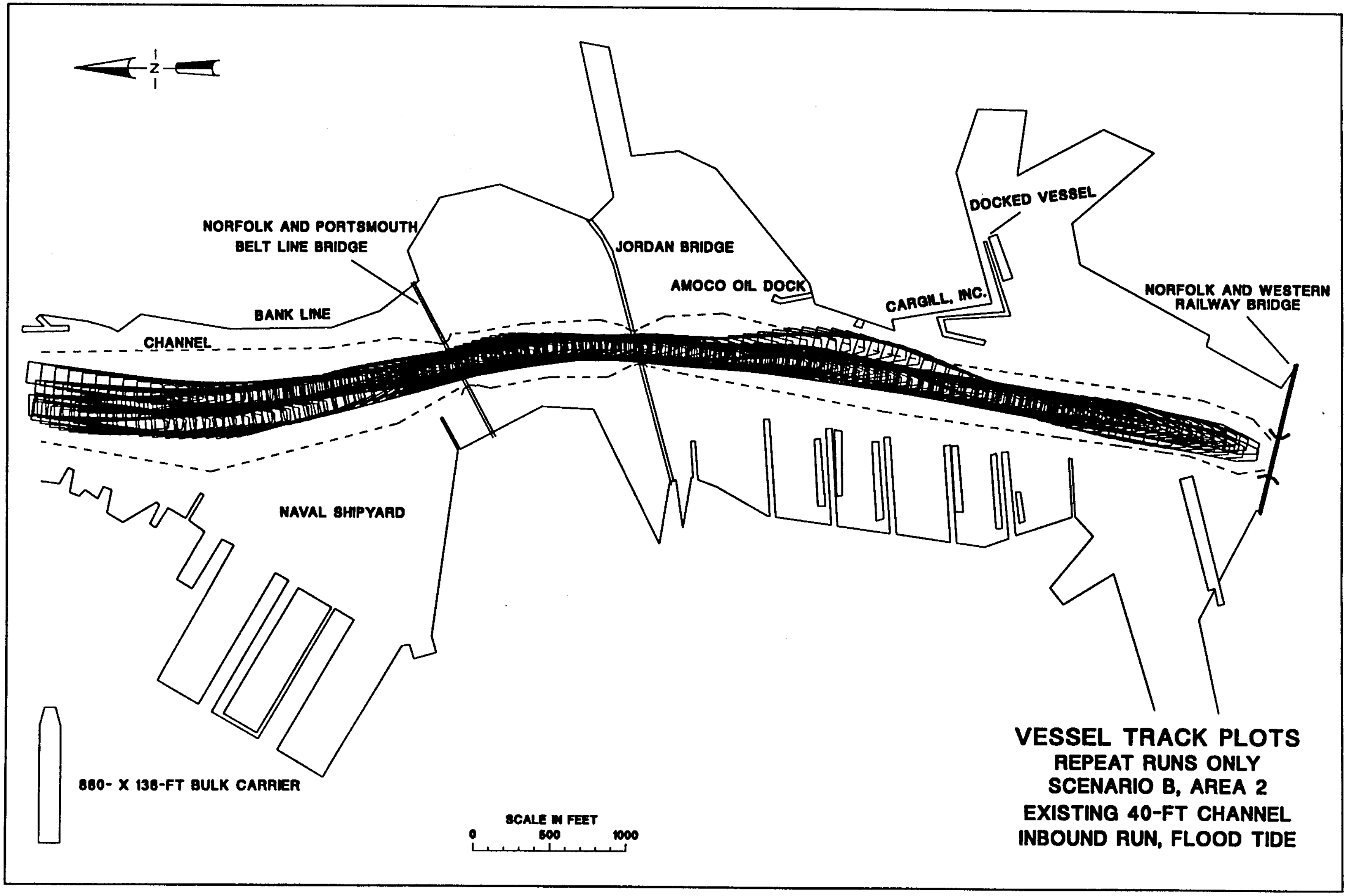

VESSEL TRACK PLOTS
SCENARIO B, AREA 2
EXISTING 40-FT CHANNEL
INBOUND RUN, FLOOD TIDE
NORFOLK AND WESTERN
RAILWAY BRIDGE
DOCKED VESSEL
CARGILL, INC.
AMOCO OIL DOCK
JORDAN BRIDGE
NORFOLK AND PORTSMOUTH
BELT LINE BRIDGE
BANK LINE
CHANNEL
NAVAL SHIPYARD
SCALE IN FEET
0
500
1000
N
880- X 136-FT BULK CARRIER

Plate 10


VESSEL TRACK PLOTS
TRANSIT THROUGH BRIDGES
EXISTING 40-FT CHANNEL
INBOUND RUN, FLOOD TIDE
JORDAN BRIDGE
CHANNEL
NORFOLK AND PORTSMOUTH
BELT LINE BRIDGE
N
SCALE IN FEET
0
500


N
DOCKED VESSEL
CHANNEL
FLOATING DRY DOCK
BANK LINE
SCALE IN FEET
0
500
1000
880- X 138-FT BULK CARRIER
VESSEL TRACK PLOTS
REPEAT RUNS ONLY
SCENARIO B, AREA 1
EXISTING 40-FT CHANNEL
INBOUND RUN, FLOOD TIDE



N
NORFOLK AND PORTSMOUTH BELT LINE BRIDGE
BANK LINE
CHANNEL
JORDAN BRIDGE
AMOCO OIL DOCK
CARGILL, INC.
DOCKED VESSEL
NORFOLK AND WESTERN RAILWAY BRIDGE
NAVAL SHIPYARD
860- X 136-FT BULK CARRIER
SCALE IN FEET
0
500
1000
VESSEL TRACK PLOTS
REPEAT RUNS ONLY
SCENARIO B, AREA 2
EXISTING 40-FT CHANNEL
INBOUND RUN, FLOOD TIDE

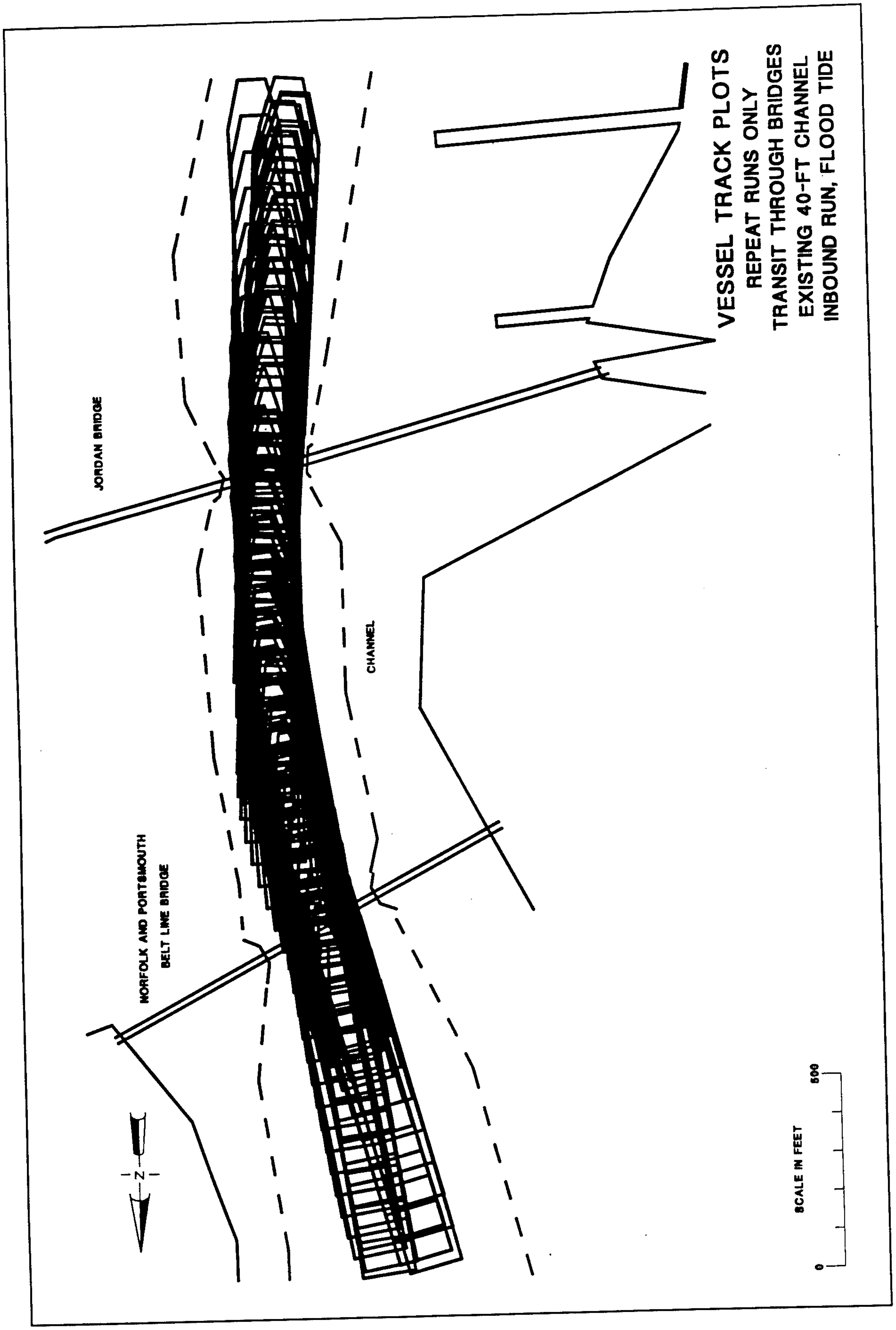
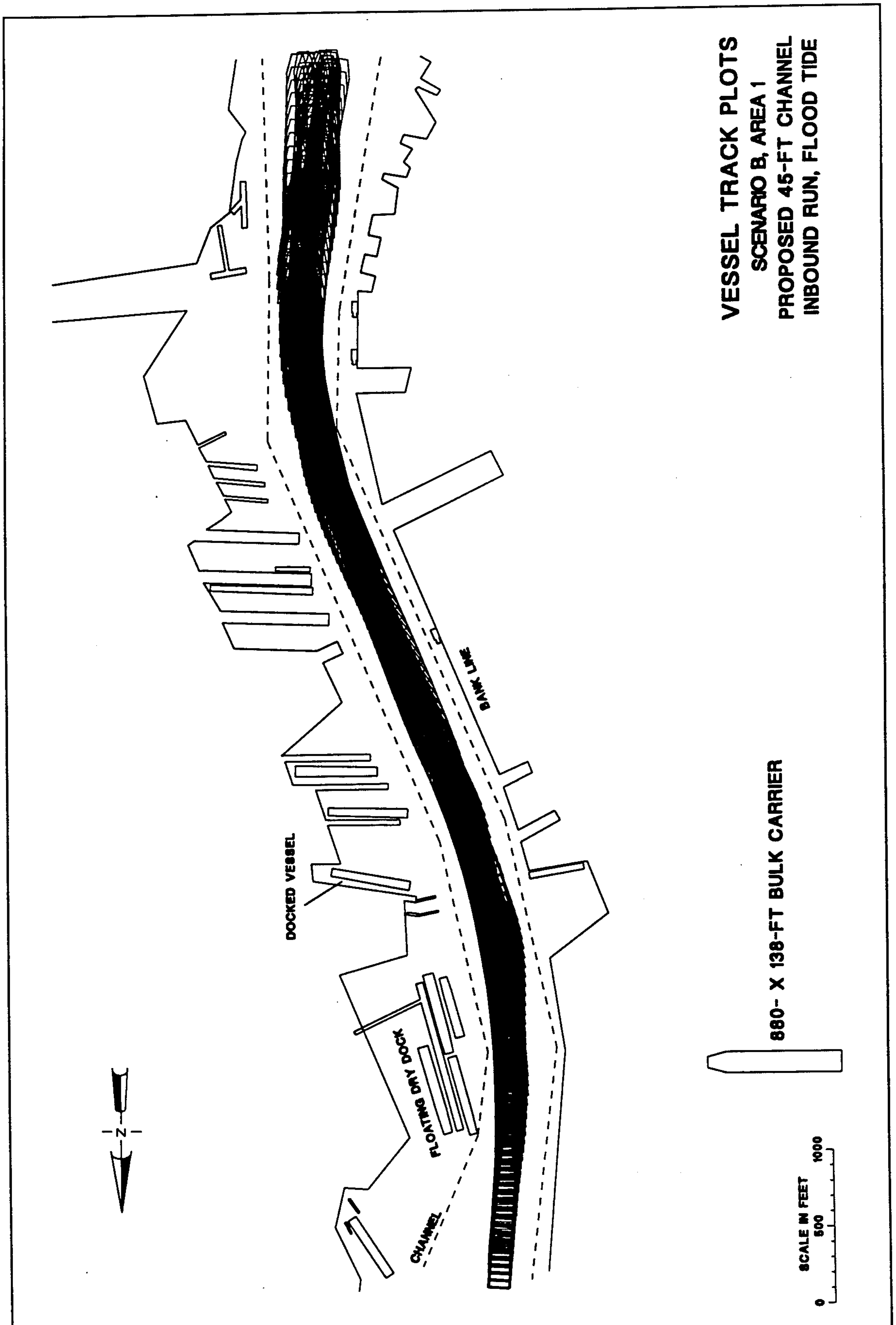

VESSEL TRACK PLOTS
REPEAT RUNS ONLY
TRANSIT THROUGH BRIDGES
EXISTING 40-FT CHANNEL
INBOUND RUN, FLOOD TIDE
JORDAN BRIDGE
CHANNEL
NORFOLK AND PORTSMOUTH
BELT LINE BRIDGE
N
SCALE IN FEET
0
500

Plate 14


VESSEL TRACK PLOTS
SCENARIO B, AREA 1
PROPOSED 45-FT CHANNEL
INBOUND RUN, FLOOD TIDE
860- X 138-FT BULK CARRIER
BANK LINE
DOCKED VESSEL
FLOATING DRY DOCK
CHANNEL
N
SCALE IN FEET
0
500
1000

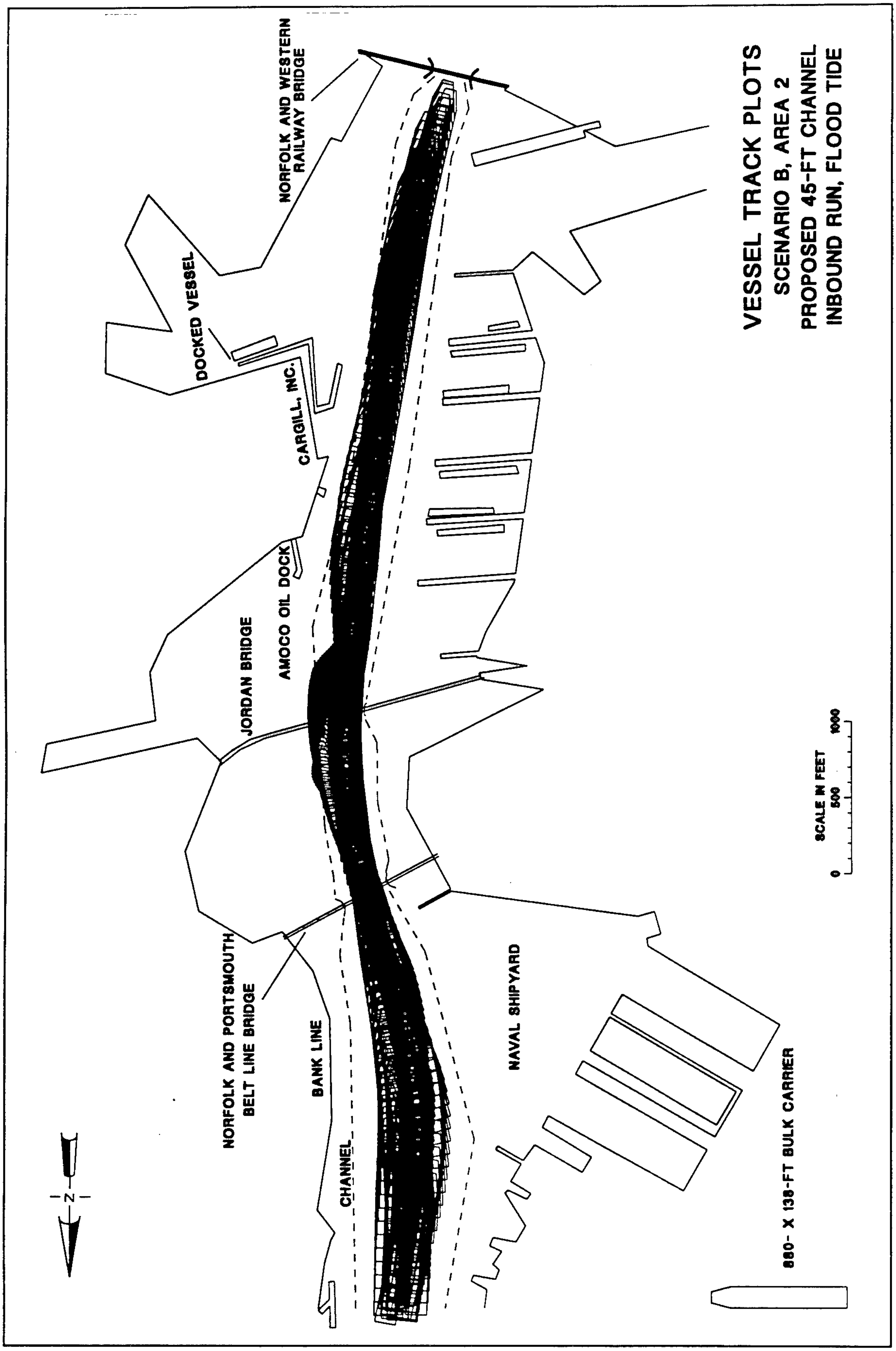
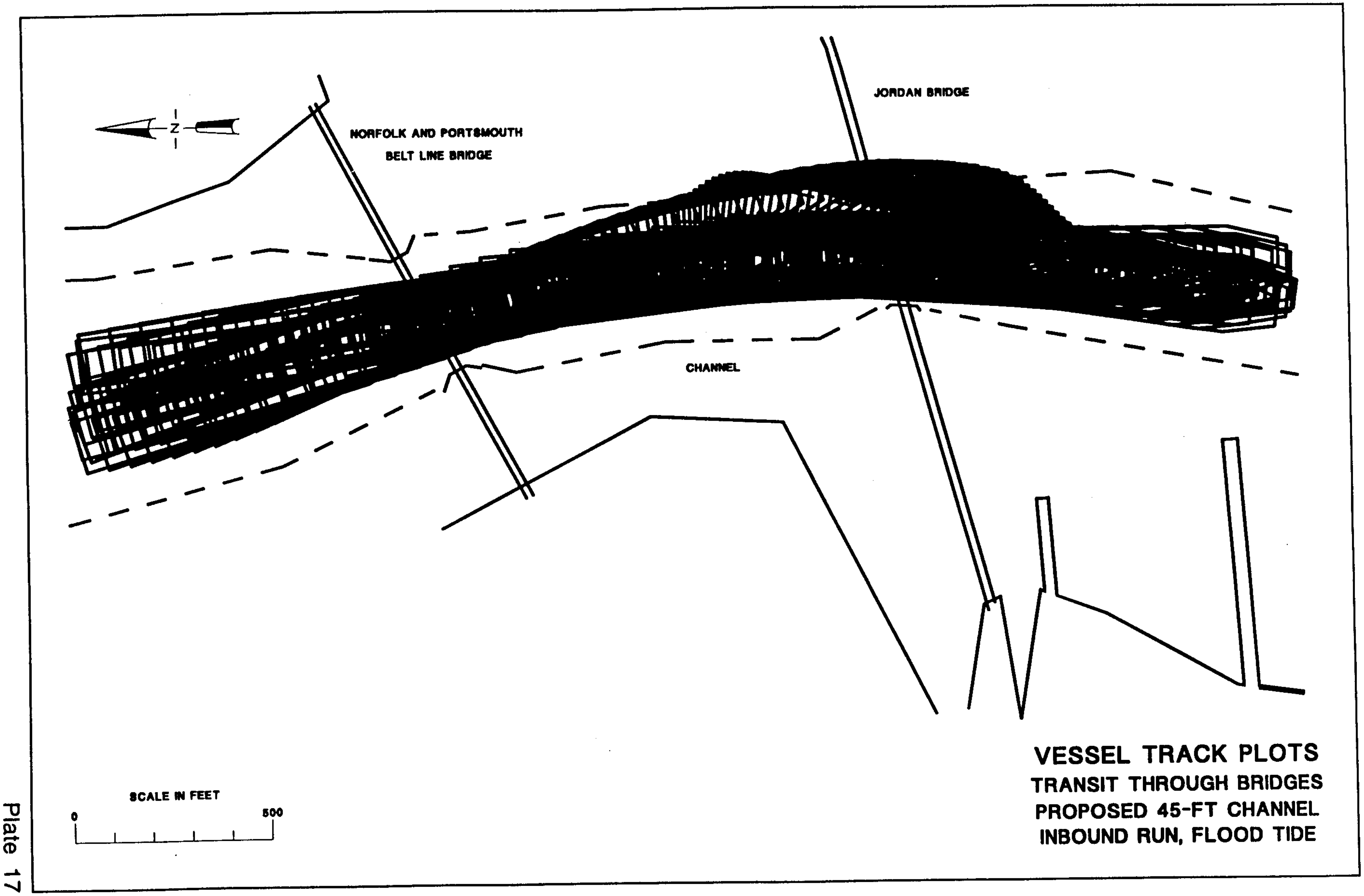

VESSEL TRACK PLOTS
SCENARIO B, AREA 2
PROPOSED 45-FT CHANNEL
INBOUND RUN, FLOOD TIDE
NORFOLK AND WESTERN RAILWAY BRIDGE
DOCKED VESSEL
CARGILL, INC.
AMOCO OIL DOCK
JORDAN BRIDGE
SCALE IN FEET
0
500
1000
NORFOLK AND PORTSMOUTH BELT LINE BRIDGE
BANK LINE
NAVAL SHIPYARD
CHANNEL
N
880- X 138-FT BULK CARRIER

Plate 16



VESSEL TRACK PLOTS
TRANSIT THROUGH BRIDGES
PROPOSED 45-FT CHANNEL
INBOUND RUN, FLOOD TIDE

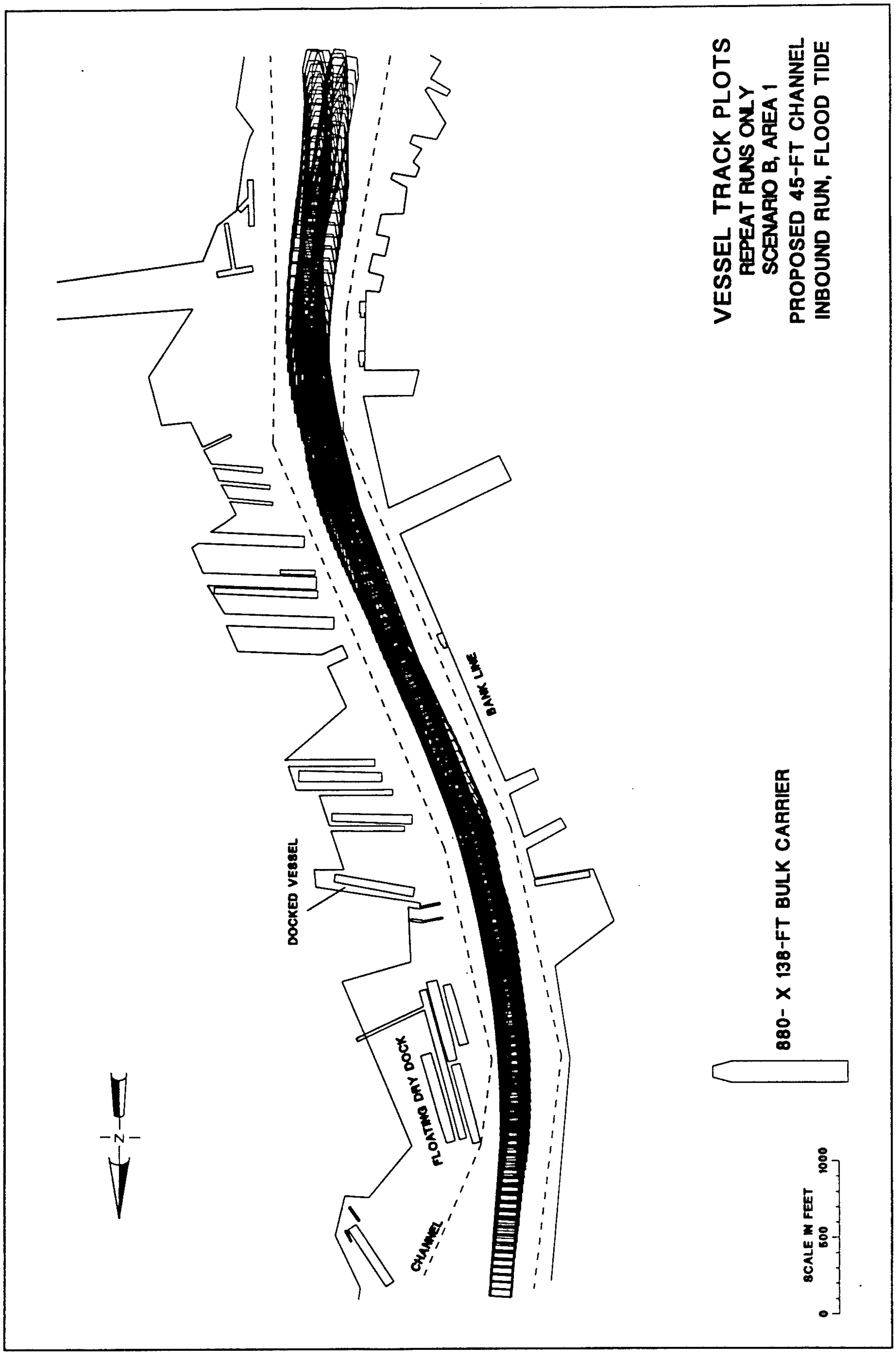
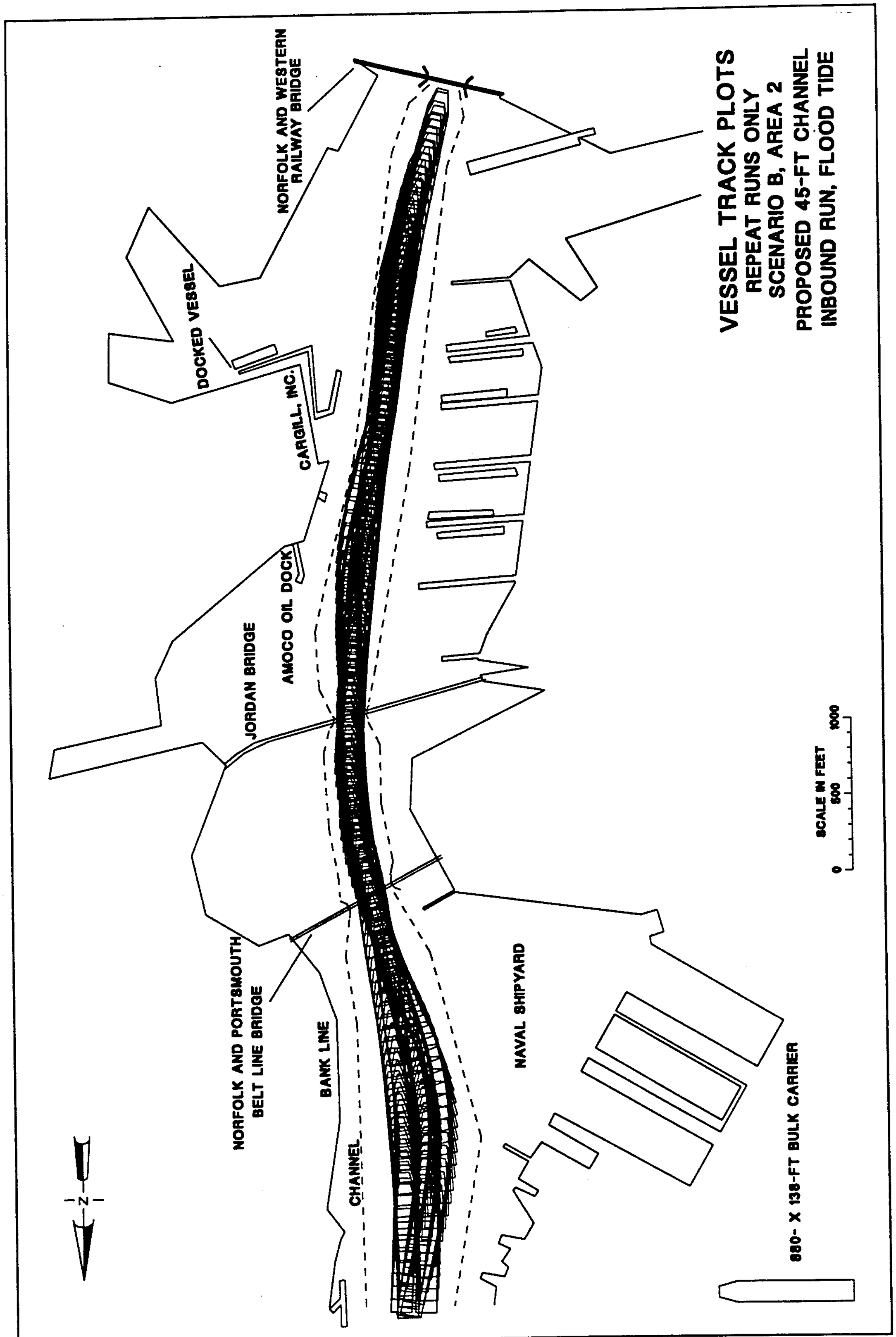

VESSEL TRACK PLOTS
REPEAT RUNS ONLY
SCENARIO B, AREA 1
PROPOSED 45-FT CHANNEL
INBOUND RUN, FLOOD TIDE
880- X 138-FT BULK CARRIER
SCALE IN FEET
0
500
1000
N
DOCKED VESSEL
FLOATING DRY DOCK
CHANNEL
BANK LINE

Plate 18


VESSEL TRACK PLOTS
REPEAT RUNS ONLY
SCENARIO B, AREA 2
PROPOSED 45-FT CHANNEL
INBOUND RUN, FLOOD TIDE
NORFOLK AND WESTERN
RAILWAY BRIDGE
DOCKED VESSEL
CARGILL, INC.
AMOCO OIL DOCK
JORDAN BRIDGE
NORFOLK AND PORTSMOUTH
BELT LINE BRIDGE
BANK LINE
CHANNEL
NAVAL SHIPYARD
SCALE IN FEET
0
500
1000
N
880- X 136-FT BULK CARRIER

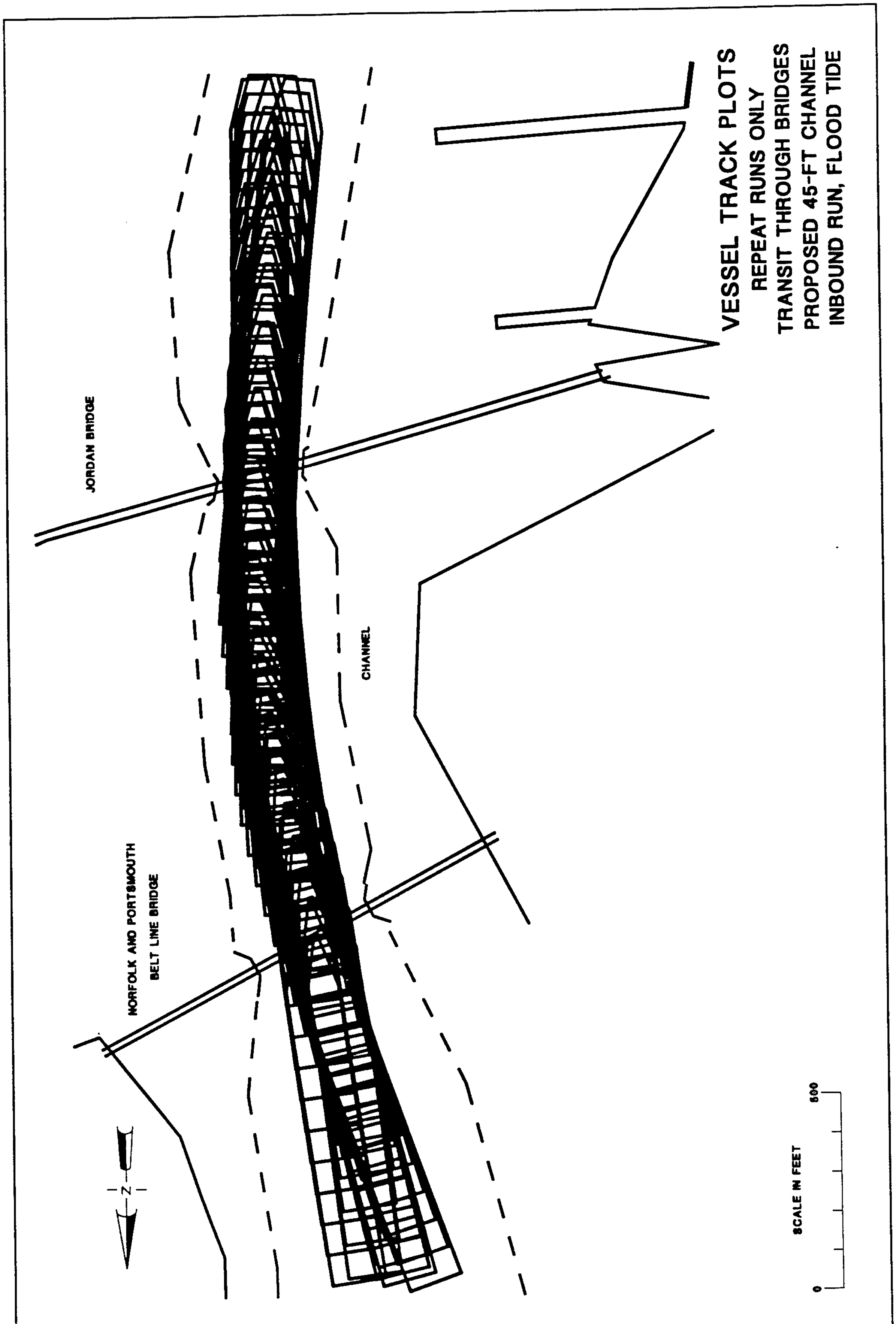
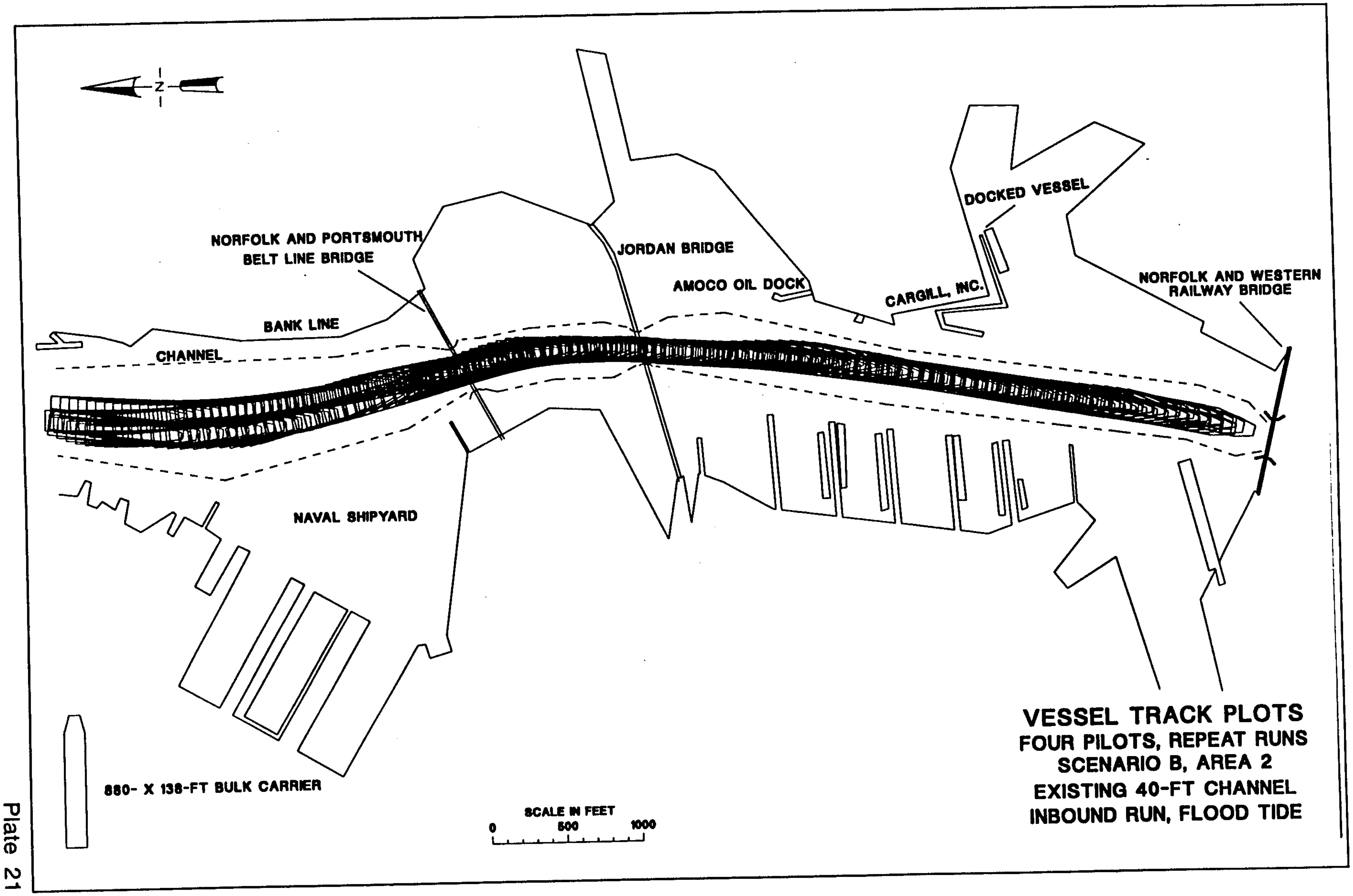
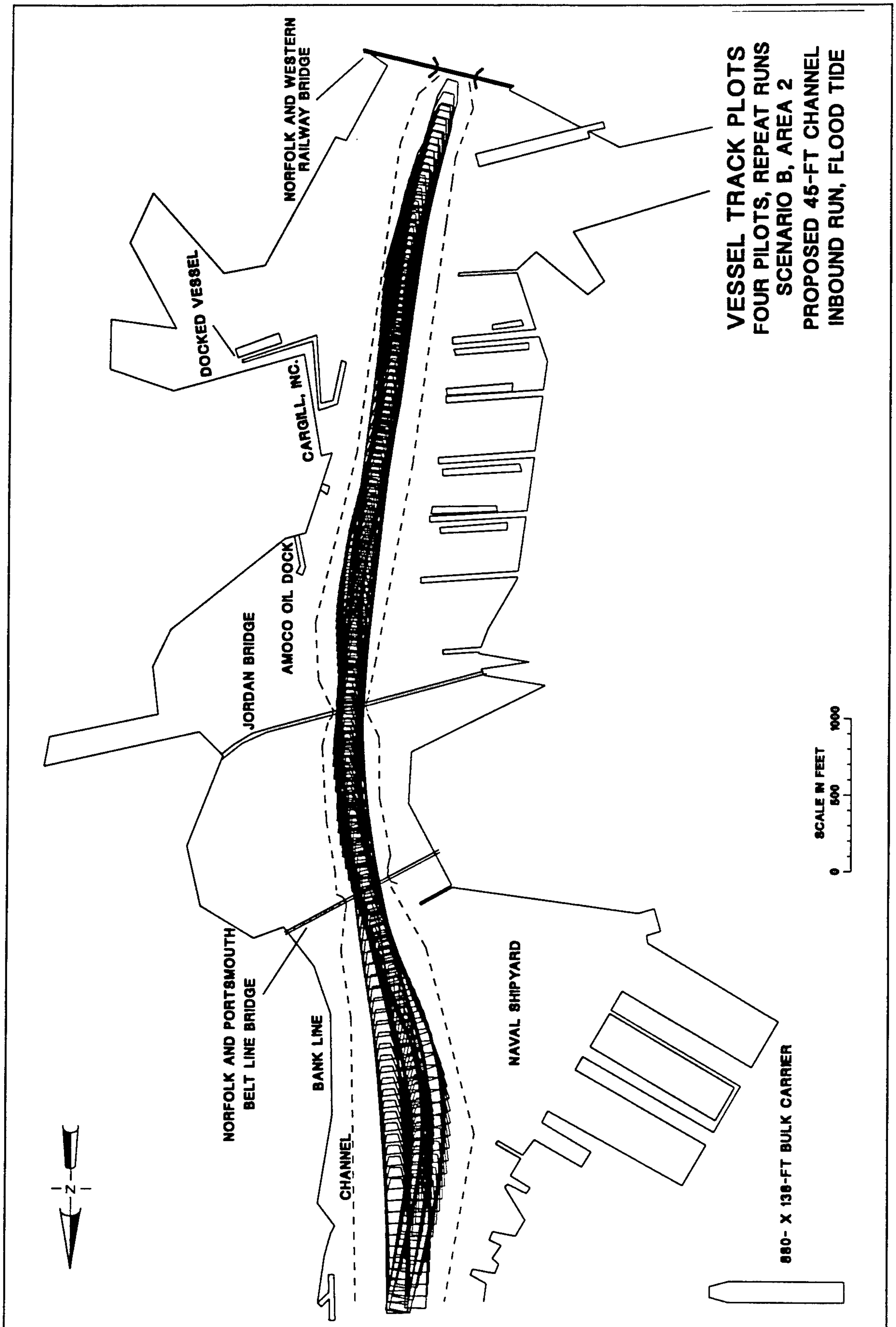

VESSEL TRACK PLOTS
REPEAT RUNS ONLY
TRANSIT THROUGH BRIDGES
PROPOSED 45-FT CHANNEL
INBOUND RUN, FLOOD TIDE
JORDAN BRIDGE
CHANNEL
NORFOLK AND PORTSMOUTH
BELT LINE BRIDGE
N
SCALE IN FEET
0
500

Plate 20

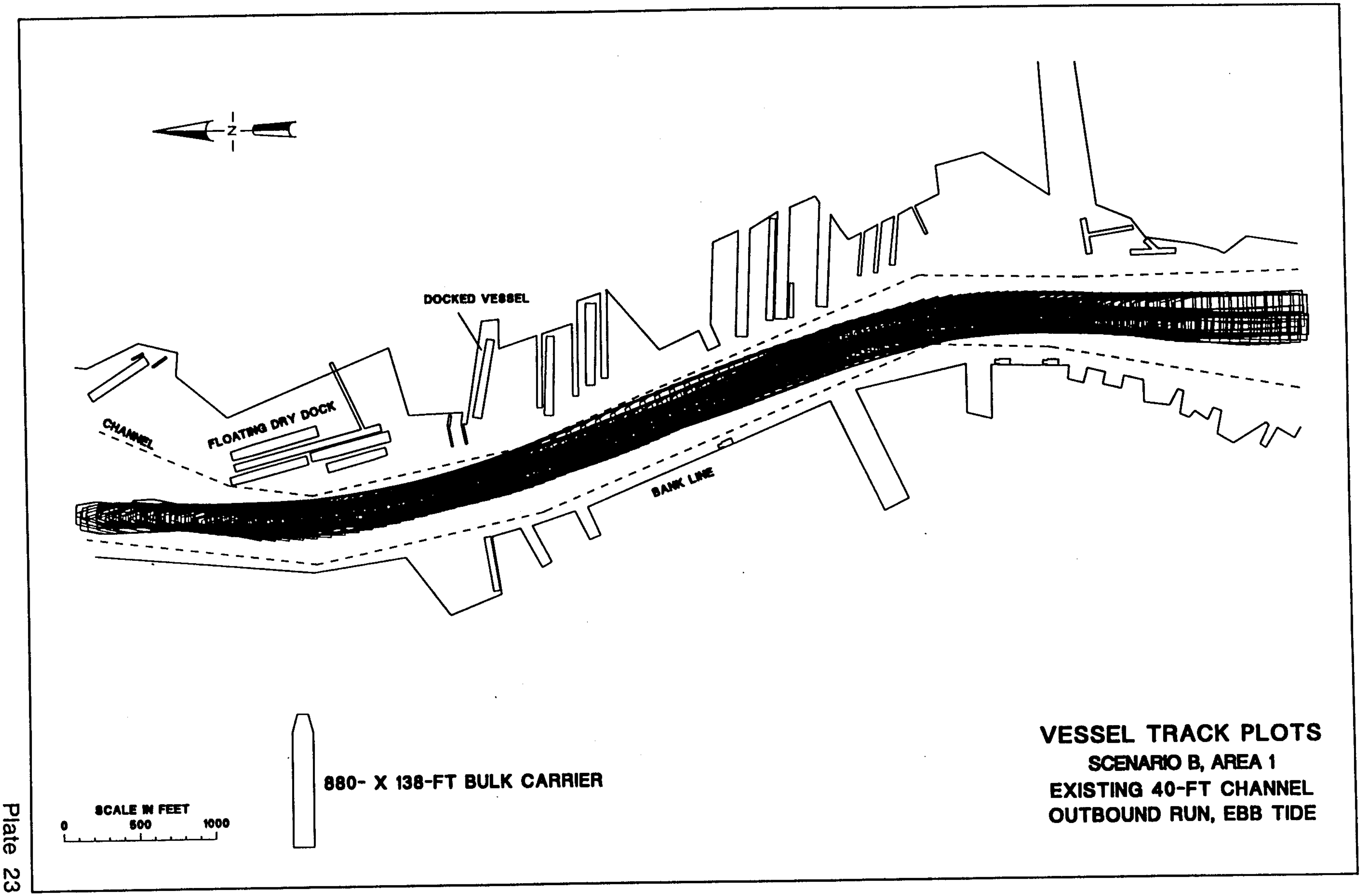


VESSEL TRACK PLOTS
FOUR PILOTS, REPEAT RUNS
SCENARIO B, AREA 2
EXISTING 40-FT CHANNEL
INBOUND RUN, FLOOD TIDE

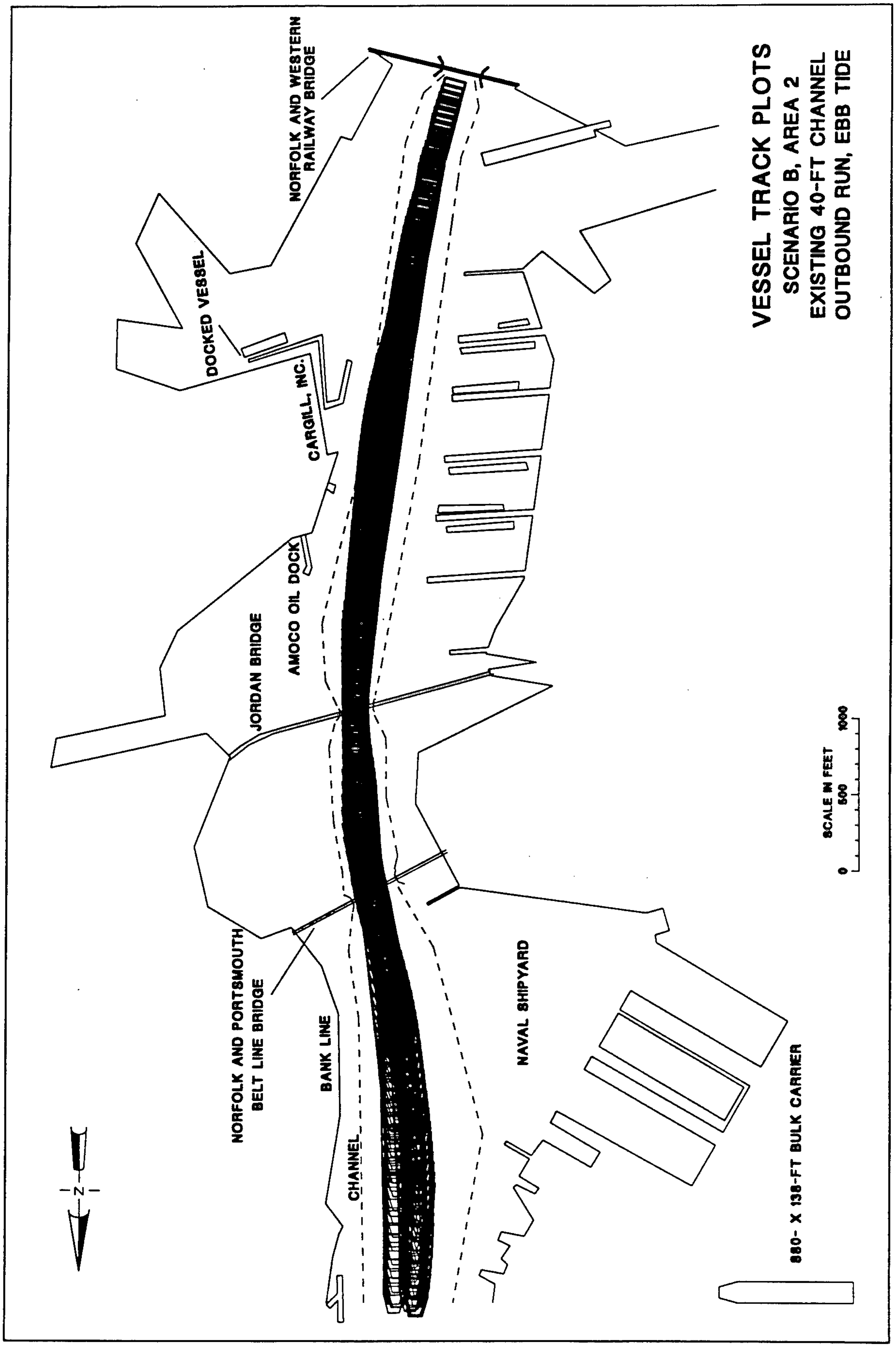


VESSEL TRACK PLOTS
FOUR PILOTS, REPEAT RUNS
SCENARIO B, AREA 2
PROPOSED 45-FT CHANNEL
INBOUND RUN, FLOOD TIDE
NORFOLK AND WESTERN RAILWAY BRIDGE
DOCKED VESSEL
CARGILL, INC.
AMOCO OIL DOCK
JORDAN BRIDGE
NORFOLK AND PORTSMOUTH BELT LINE BRIDGE
BANK LINE
NAVAL SHIPYARD
CHANNEL
SCALE IN FEET
0
500
1000
N
880- X 136-FT BULK CARRIER

Plate 22

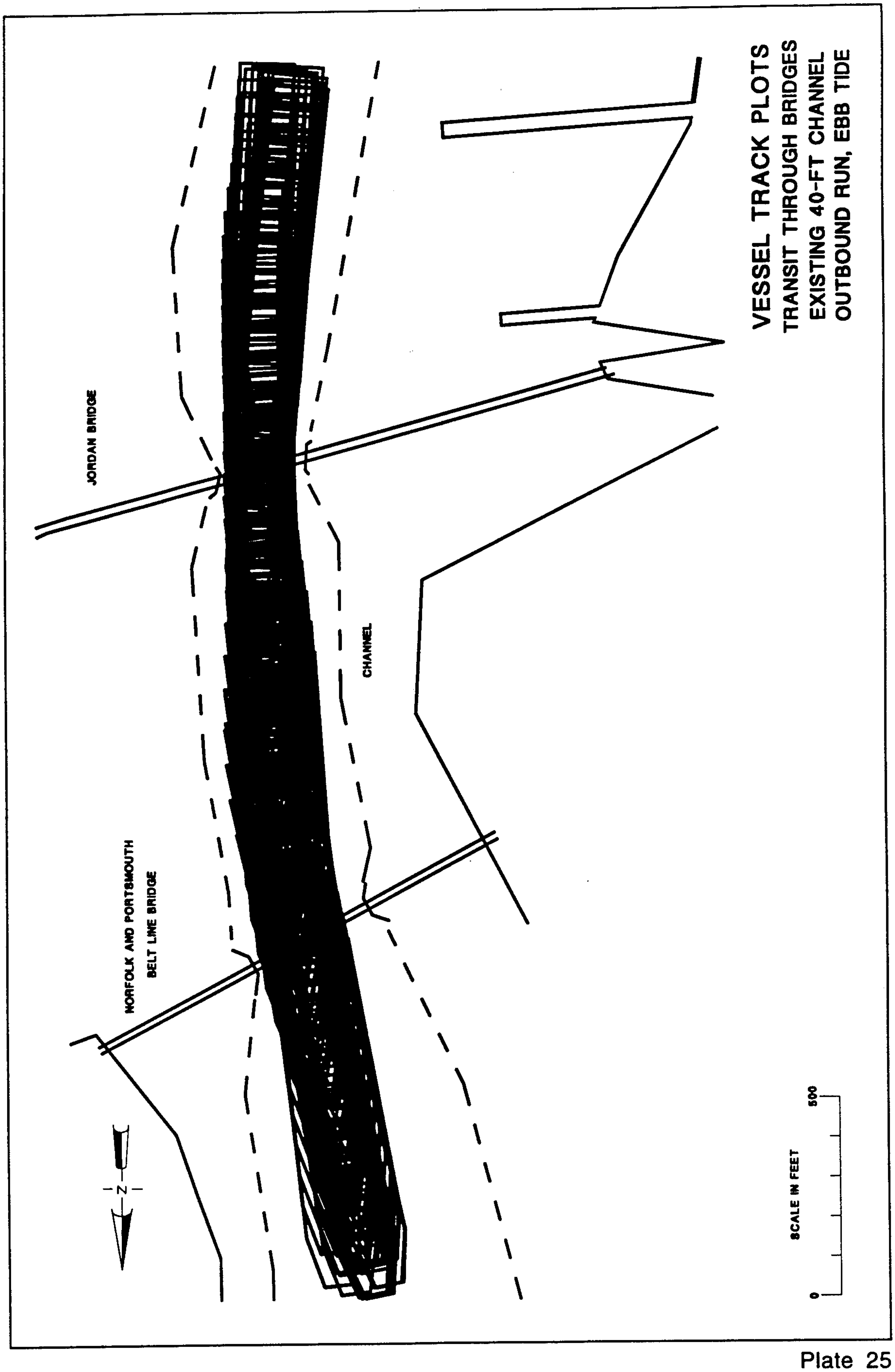


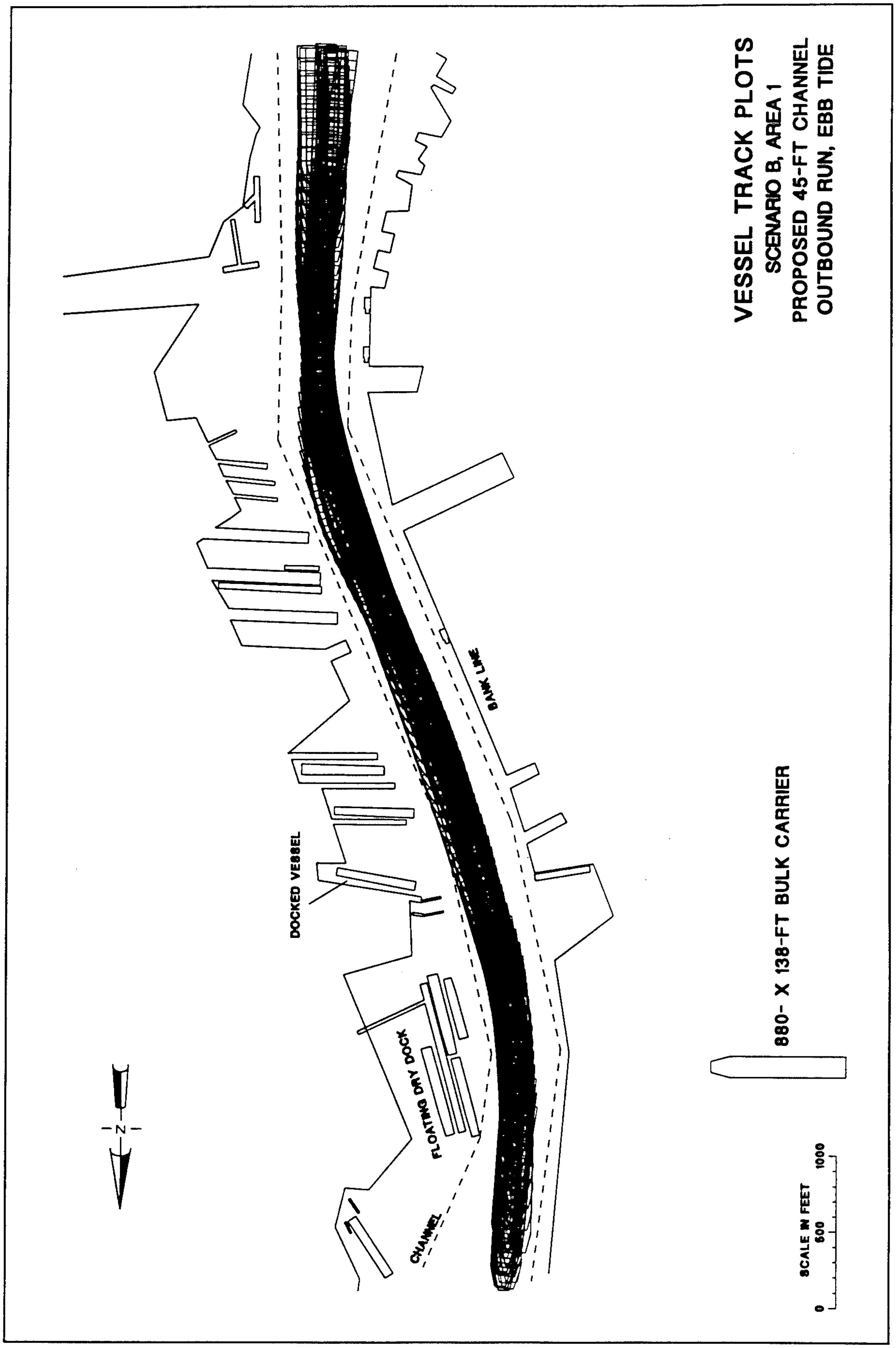
N
DOCKED VESSEL
FLOATING DRY DOCK
CHANNEL
BANK LINE
880- X 138-FT BULK CARRIER
SCALE IN FEET
0
500
1000
VESSEL TRACK PLOTS
SCENARIO B, AREA 1
EXISTING 40-FT CHANNEL
OUTBOUND RUN, EBB TIDE



VESSEL TRACK PLOTS
SCENARIO B, AREA 2
EXISTING 40-FT CHANNEL
OUTBOUND RUN, EBB TIDE
NORFOLK AND WESTERN
RAILWAY BRIDGE
DOCKED VESSEL
CARGILL, INC.
AMOCO OIL DOCK
JORDAN BRIDGE
NORFOLK AND PORTSMOUTH
BELT LINE BRIDGE
BANK LINE
CHANNEL
NAVAL SHIPYARD
880- X 136-FT BULK CARRIER
SCALE IN FEET
0
500
1000
N

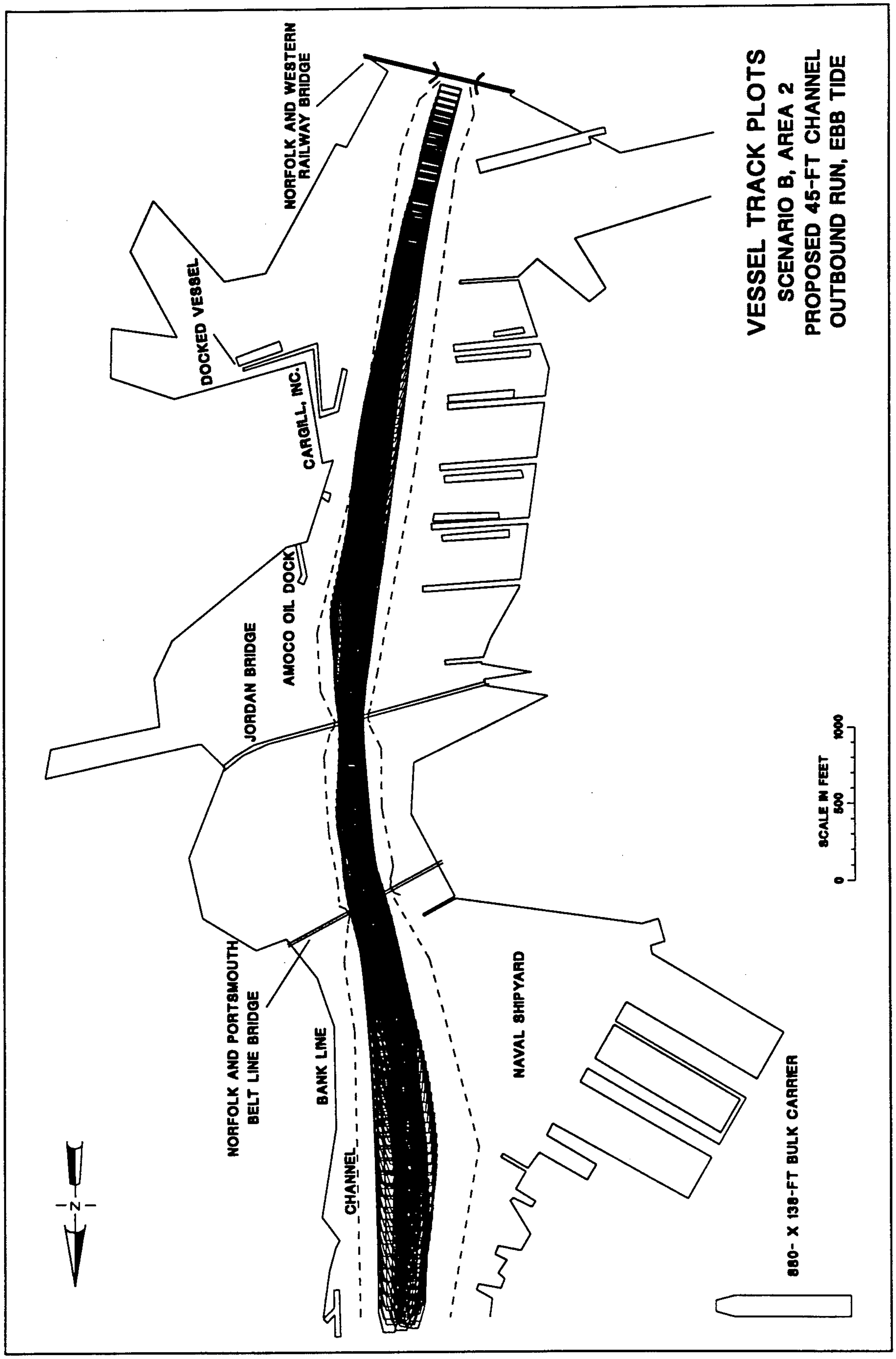
Plate 24


VESSEL TRACK PLOTS
TRANSIT THROUGH BRIDGES
EXISTING 40-FT CHANNEL
OUTBOUND RUN, EBB TIDE
JORDAN BRIDGE
CHANNEL
NORFOLK AND PORTSMOUTH
BELT LINE BRIDGE
N
SCALE IN FEET
0
500



VESSEL TRACK PLOTS
SCENARIO B, AREA 1
PROPOSED 45-FT CHANNEL
OUTBOUND RUN, EBB TIDE
880- X 138-FT BULK CARRIER
DOCKED VESSEL
BANK LINE
FLOATING DRY DOCK
CHANNEL
N
SCALE IN FEET
0
500
1000

Plate 26


VESSEL TRACK PLOTS
SCENARIO B, AREA 2
PROPOSED 45-FT CHANNEL
OUTBOUND RUN, EBB TIDE
NORFOLK AND WESTERN RAILWAY BRIDGE
DOCKED VESSEL
CARGILL, INC.
AMOCO OIL DOCK
JORDAN BRIDGE
NORFOLK AND PORTSMOUTH BELT LINE BRIDGE
BANK LINE
CHANNEL
NAVAL SHIPYARD
SCALE IN FEET
0
500
1000
N
860- X 136-FT BULK CARRIER

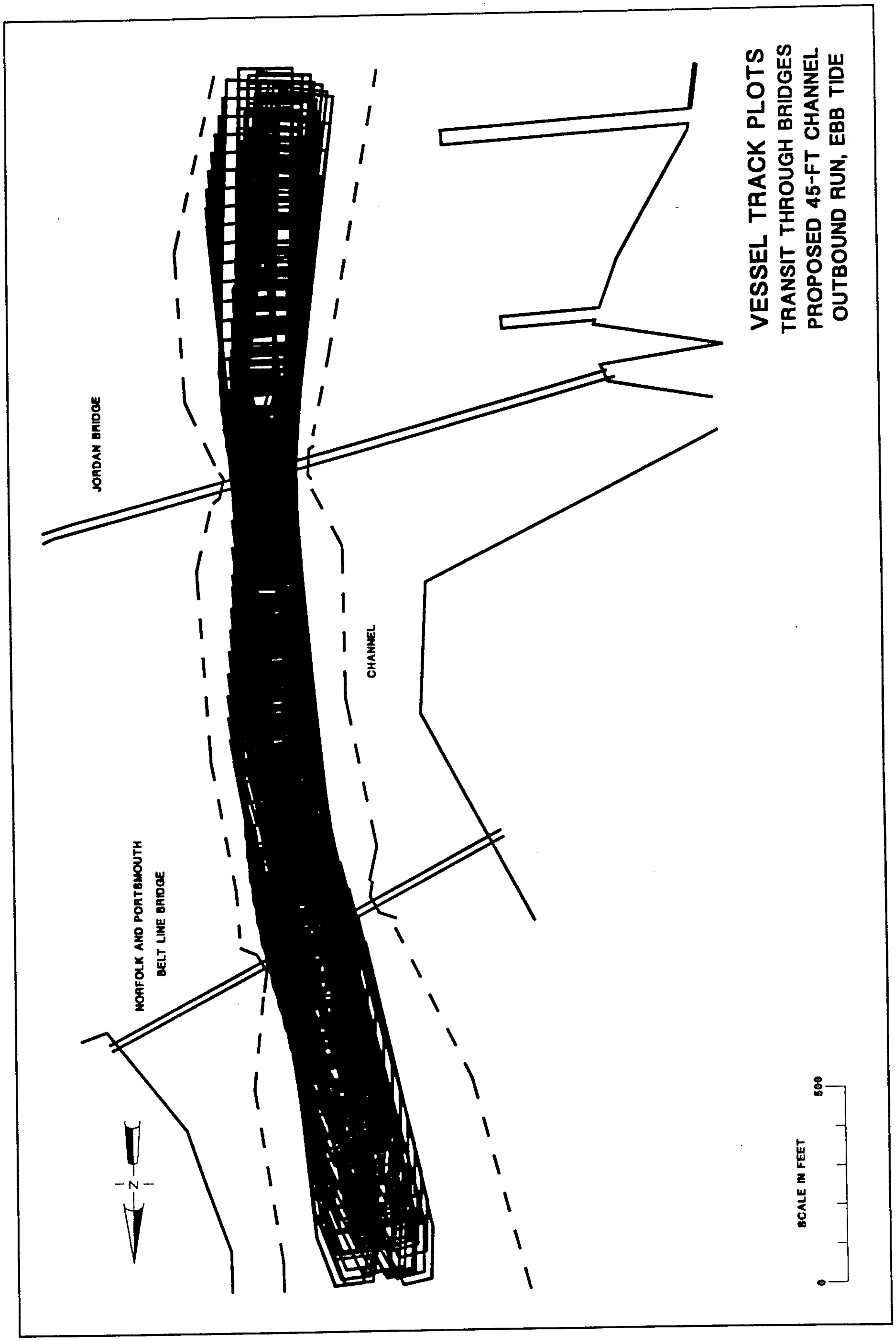
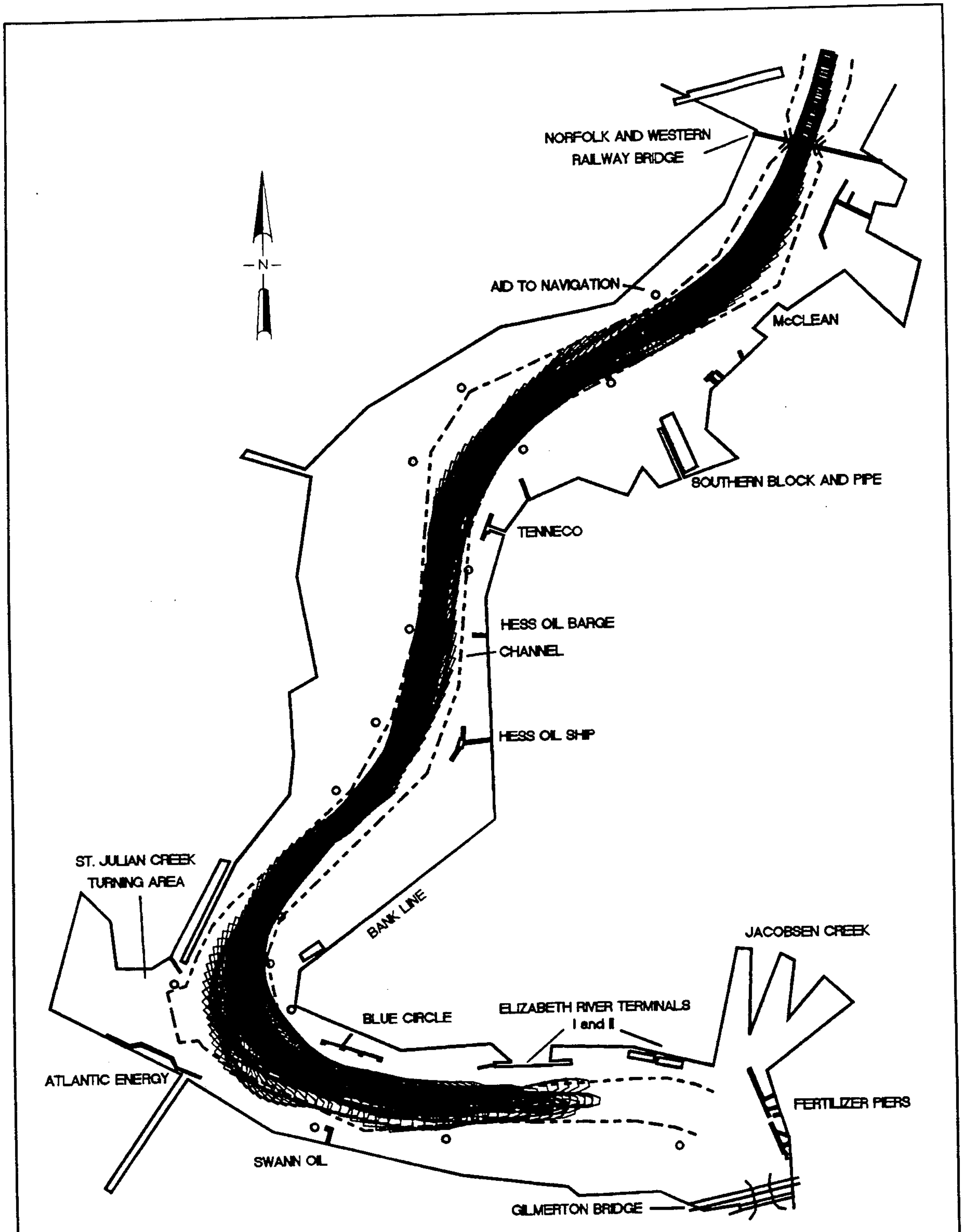
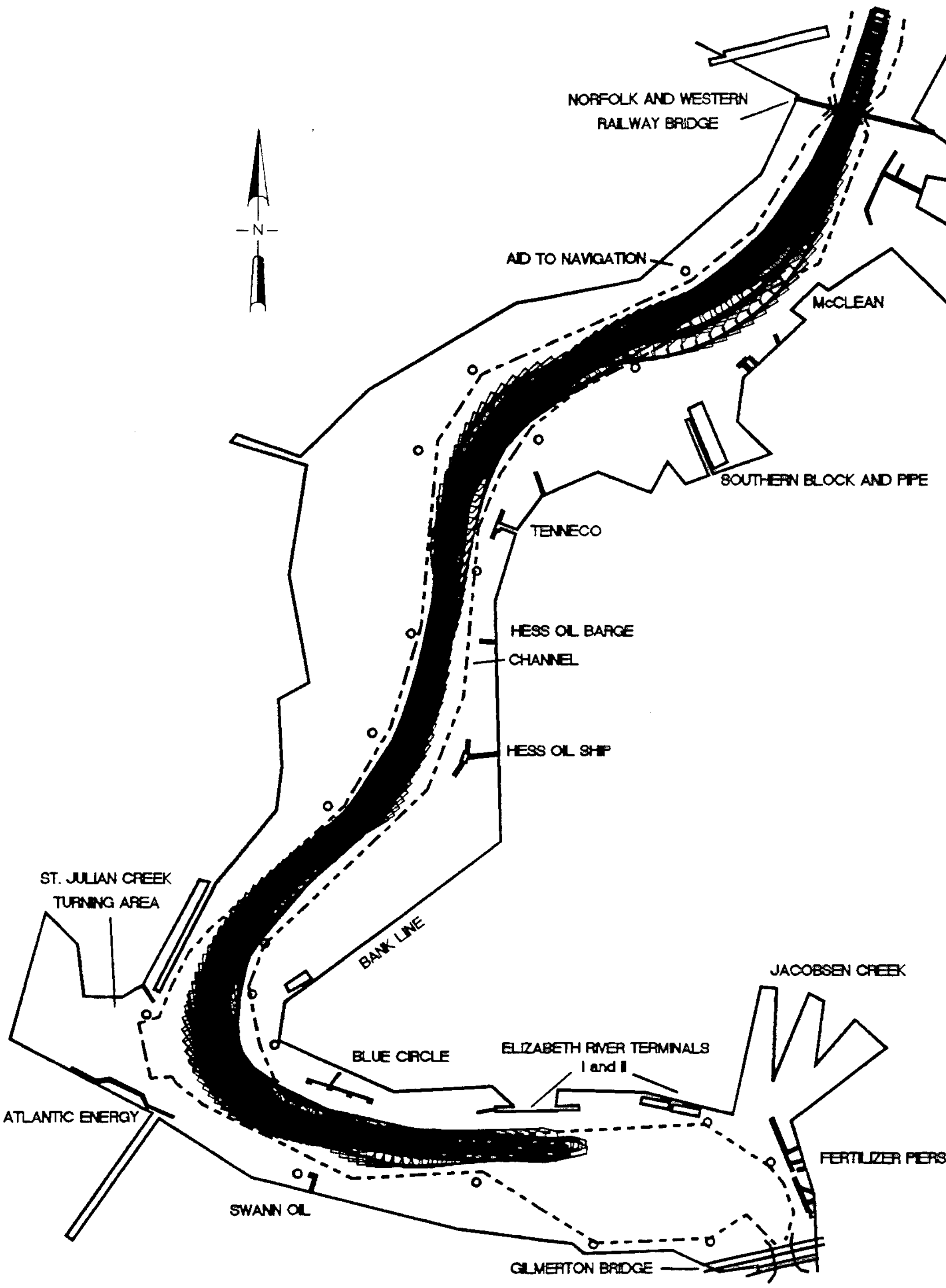

VESSEL TRACK PLOTS
TRANSIT THROUGH BRIDGES
PROPOSED 45-FT CHANNEL
OUTBOUND RUN, EBB TIDE
JORDAN BRIDGE
CHANNEL
NORFOLK AND PORTSMOUTH
BELT LINE BRIDGE
N
SCALE IN FEET
0
500

Plate 28



PILOT TRACK PLOTS
SCENARIO C, 775' X 106' BULK CARRIER
EXISTING 35' CHANNEL, INBOUND RUN, FLOOD TIDE

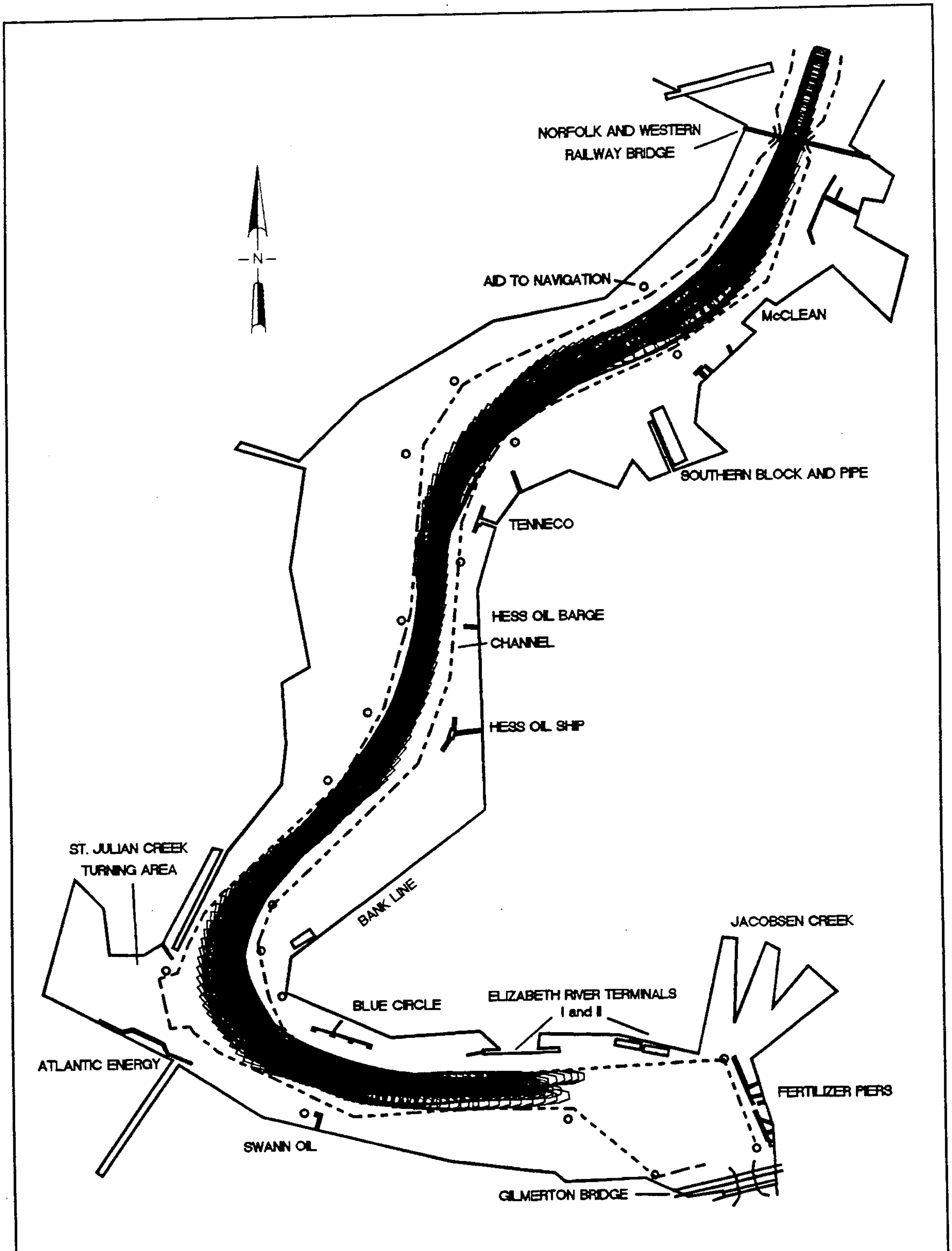


PILOT TRACK PLOTS

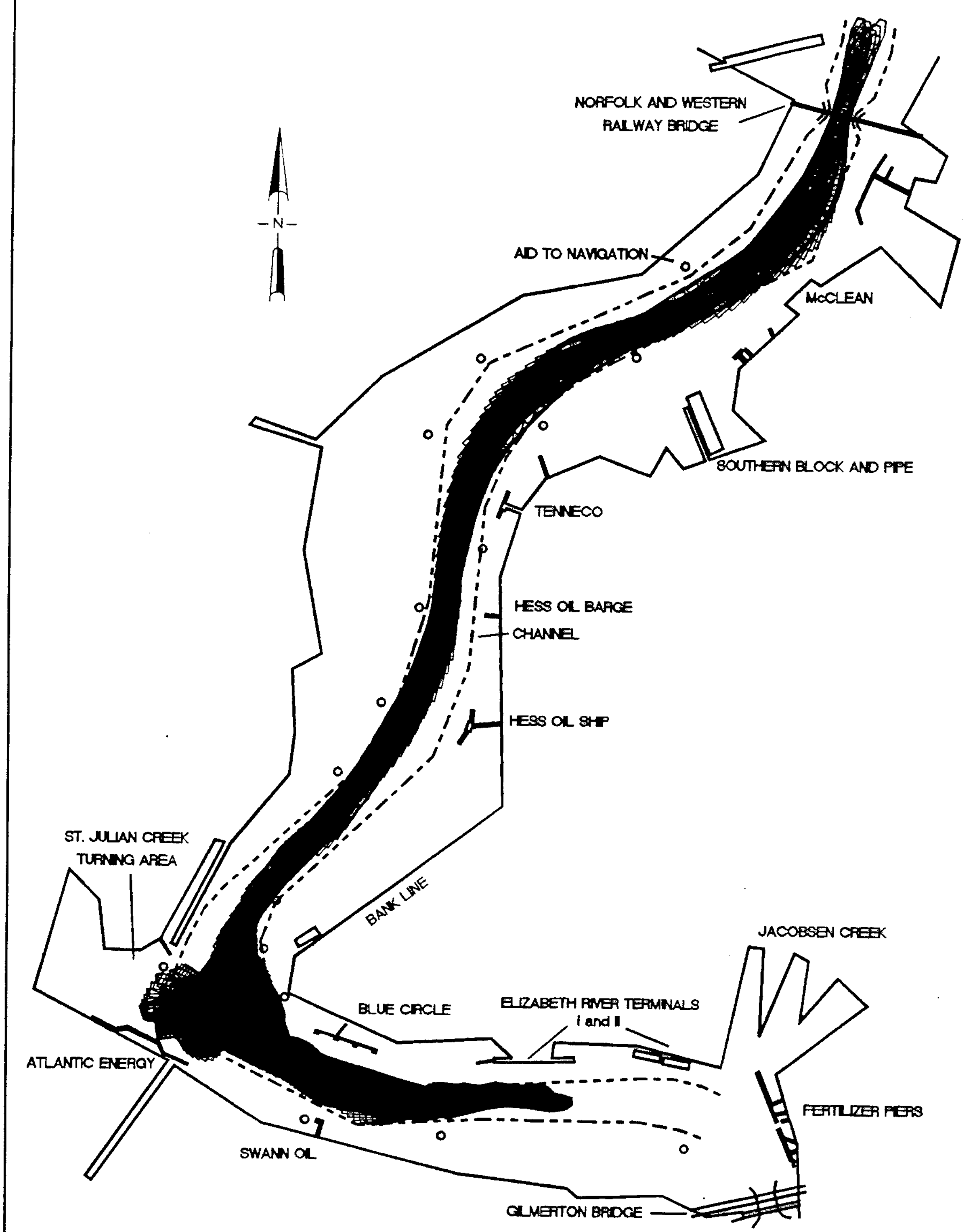
SCENARIO C, 775' X 106' BULK CARRIER

PLAN 1, 40' CHANNEL, INBOUND RUN, FLOOD TIDE

SCALE IN FEET
0 500 1000

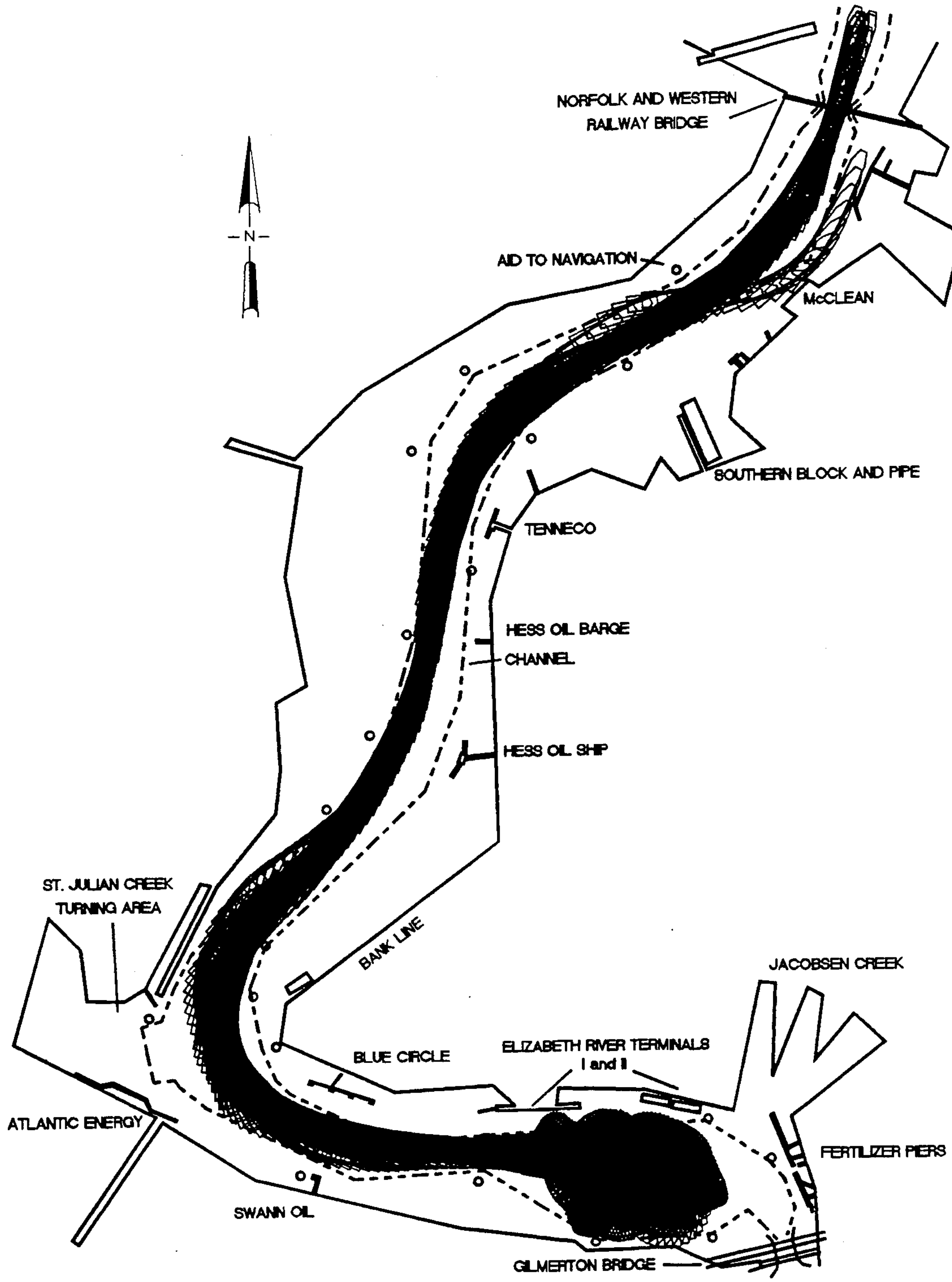


PILOT TRACK PLOTS
SCENARIO C, 775' X 106' BULK CARRIER
PLAN 2, 40' CHANNEL, INBOUND RUN, FLOOD TIDE

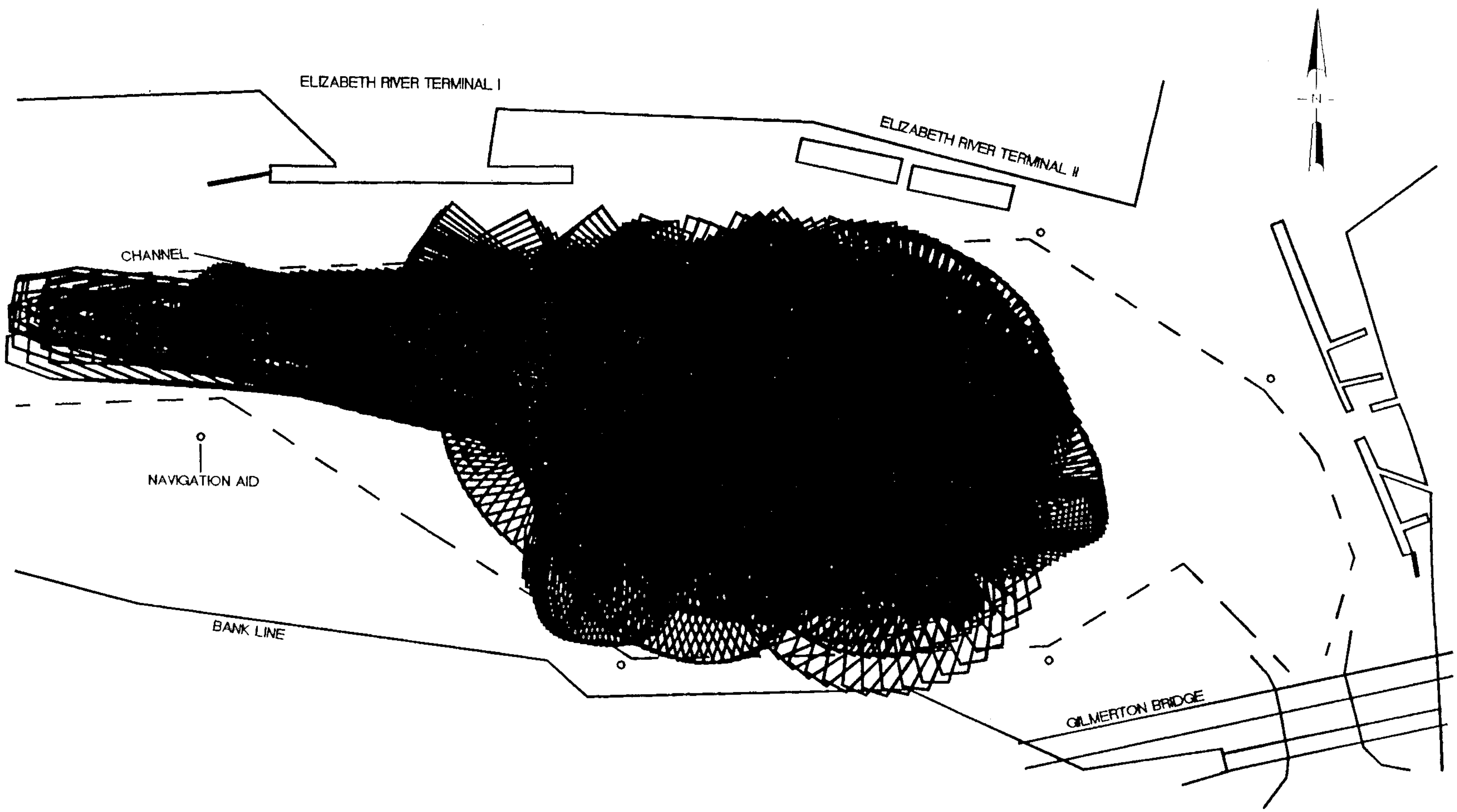


PILOT TRACK PLOTS
SCENARIO C, 775' X 106' BULK CARRIER
EXISTING 35' CHANNEL, OUTBOUND RUN, EBB TIDE

Plate 32



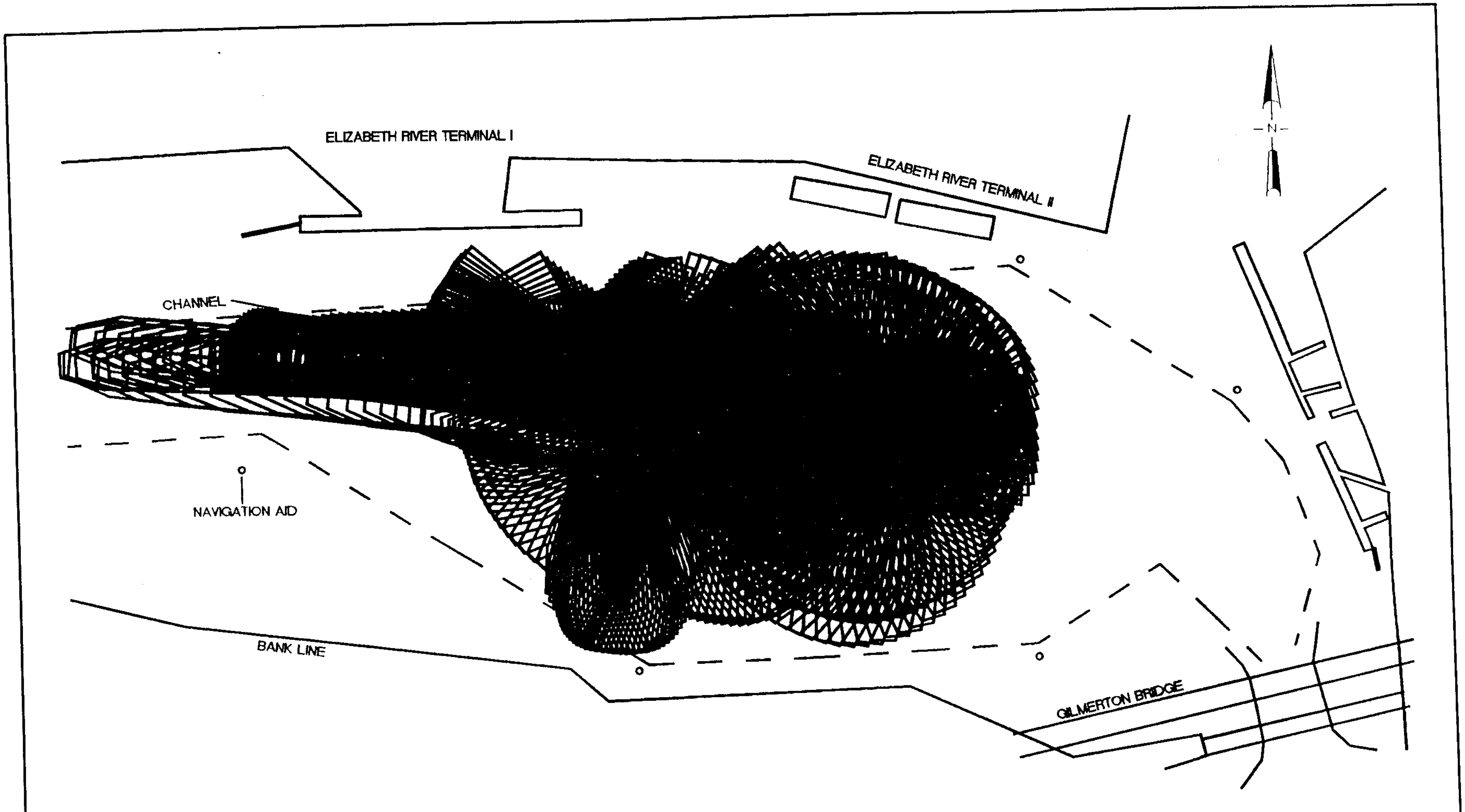
PILOT TRACK PLOTS
SCENARIO C, 775' X 106' BULK CARRIER
PLAN 1, 40' CHANNEL, OUTBOUND RUN, EBB TIDE



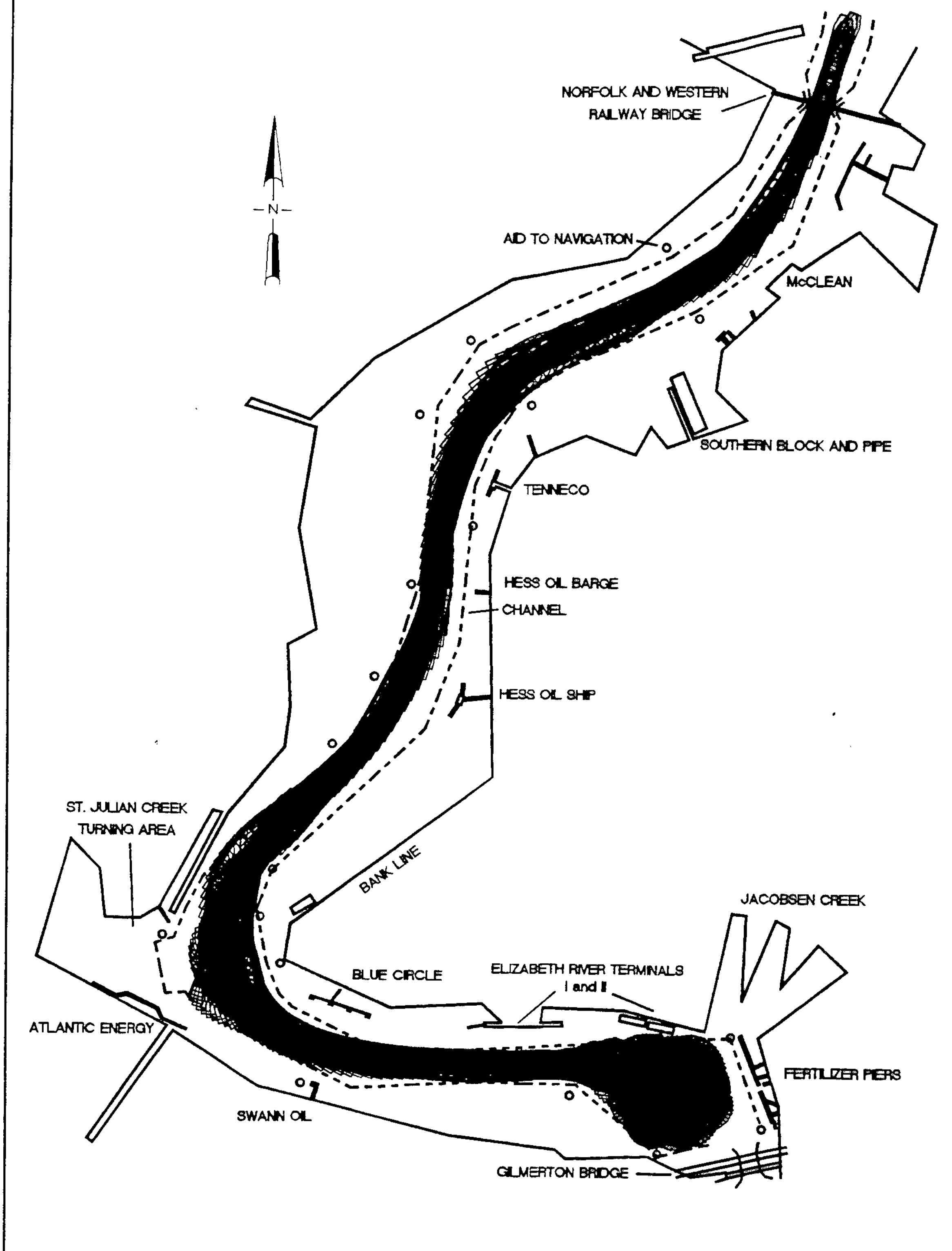
PILOT TRACK PLOTS

TURNING BASIN, 775' X 106' BULK CARRIER

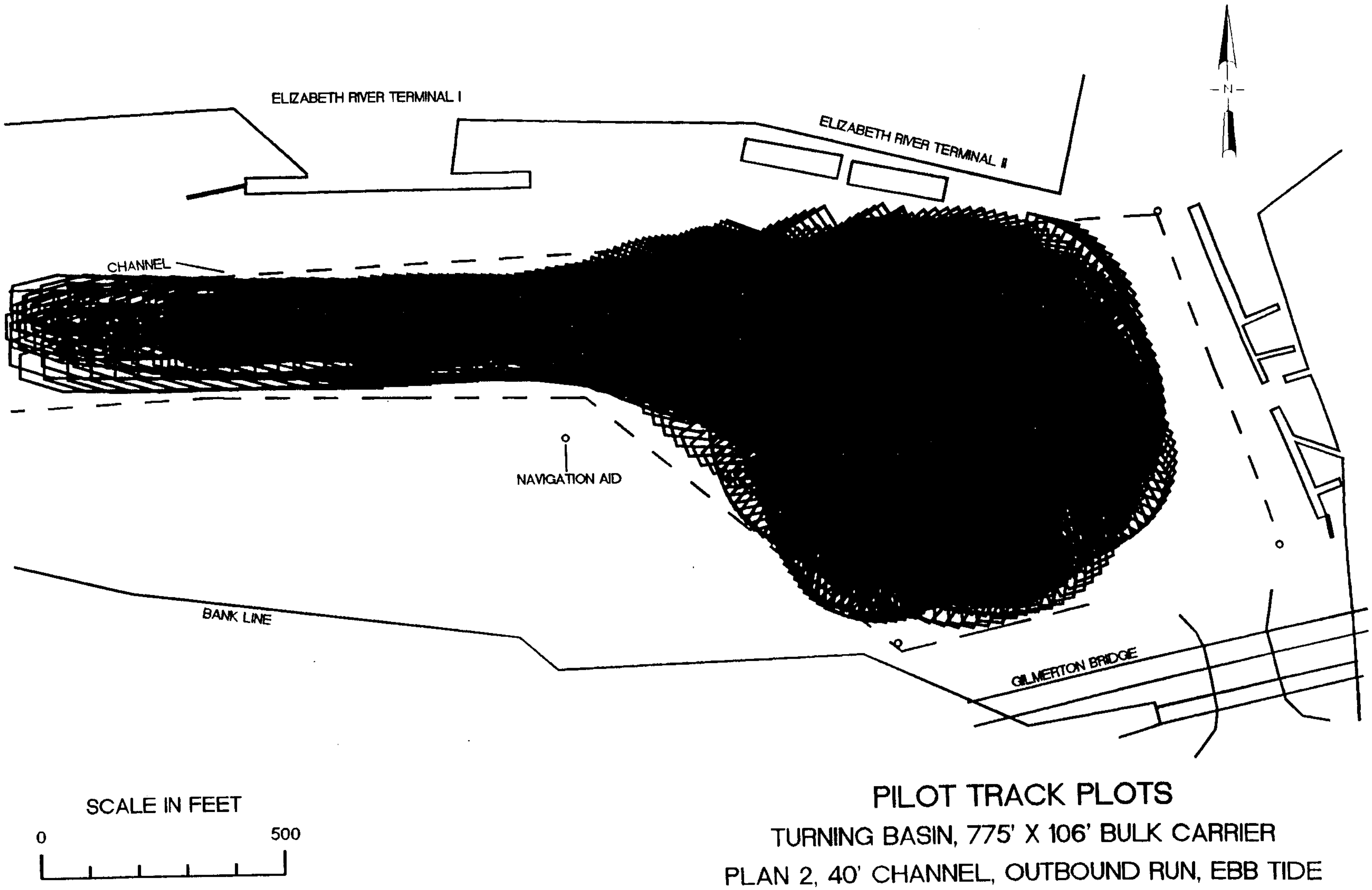
PLAN 1, 40' CHANNEL, OUTBOUND RUN, EBB TIDE



PILOT TRACK PLOTS
TURNING BASIN, 775' X 106' BULK CARRIER, REPEAT RUNS
PLAN 1, 40' CHANNEL, OUTBOUND RUN, EBB TIDE



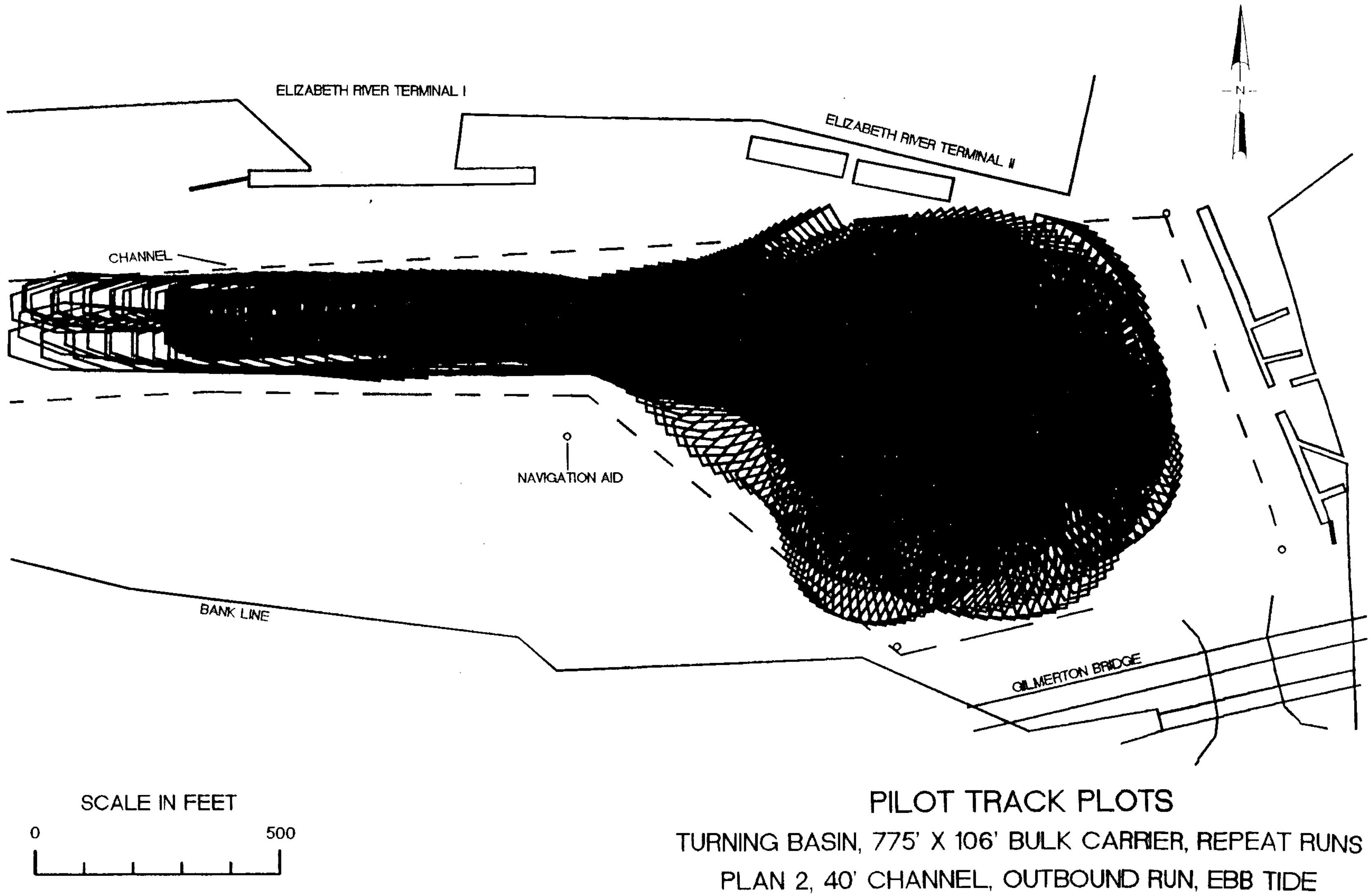
PILOT TRACK PLOTS
SCENARIO C. 775' X 106' BULK CARRIER
PLAN 2, 40' CHANNEL, OUTBOUND RUN, EBB TIDE



PILOT TRACK PLOTS

TURNING BASIN, 775' X 106' BULK CARRIER

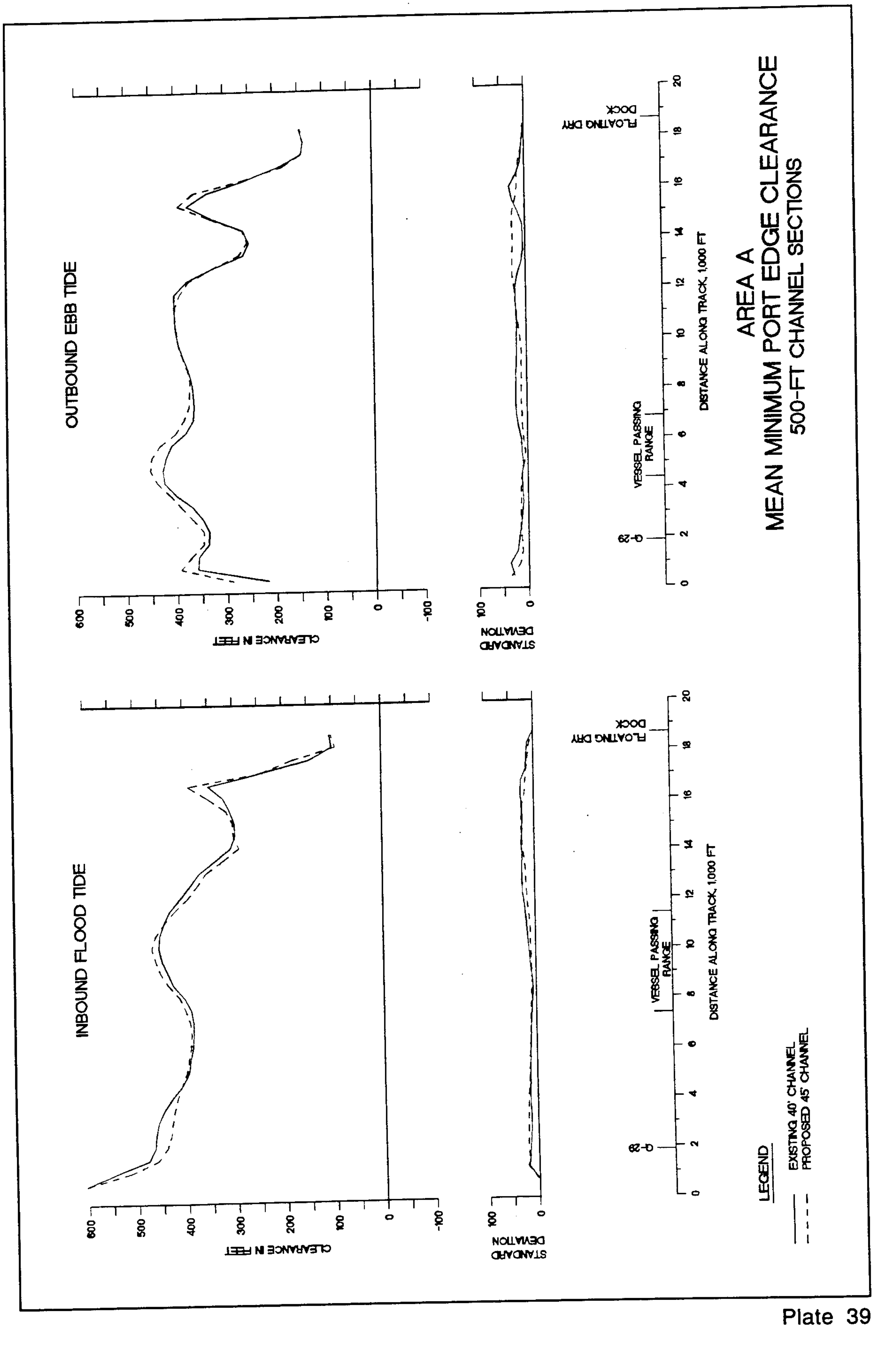
PLAN 2, 40' CHANNEL, OUTBOUND RUN, EBB TIDE

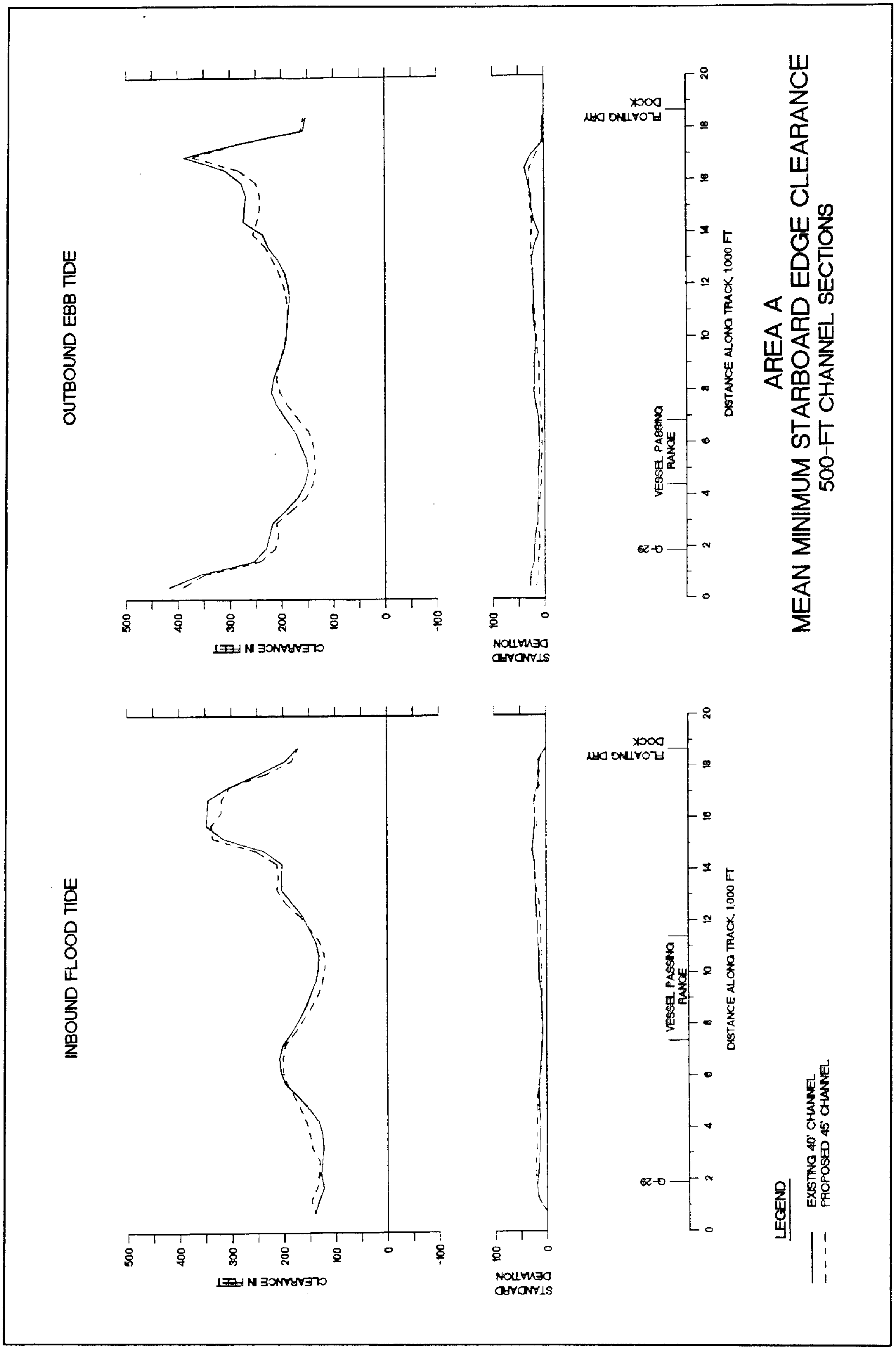


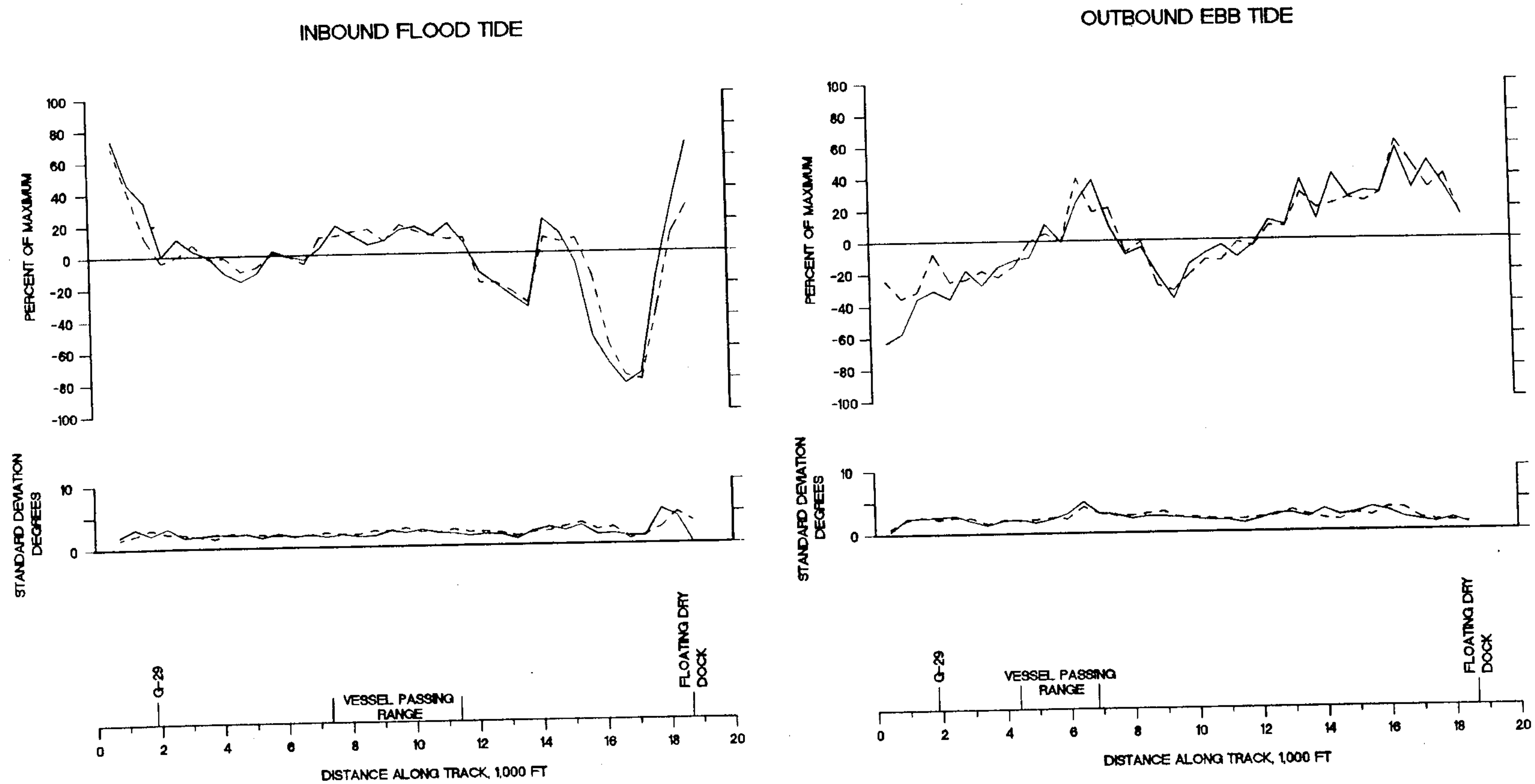
PILOT TRACK PLOTS

TURNING BASIN, 775' X 106' BULK CARRIER, REPEAT RUNS

PLAN 2, 40' CHANNEL, OUTBOUND RUN, EBB TIDE


AREA A
MEAN MINIMUM PORT EDGE CLEARANCE
500-FT CHANNEL SECTIONS
OUTBOUND EBB TIDE
INBOUND FLOOD TIDE
CLEARANCE IN FEET
STANDARD DEVIATION
DISTANCE ALONG TRACK, 1,000 FT
VESSEL PASSING RANGE
FLOATING DRY DOCK
Q-29
LEGEND
EXISTING 40' CHANNEL
PROPOSED 45' CHANNEL

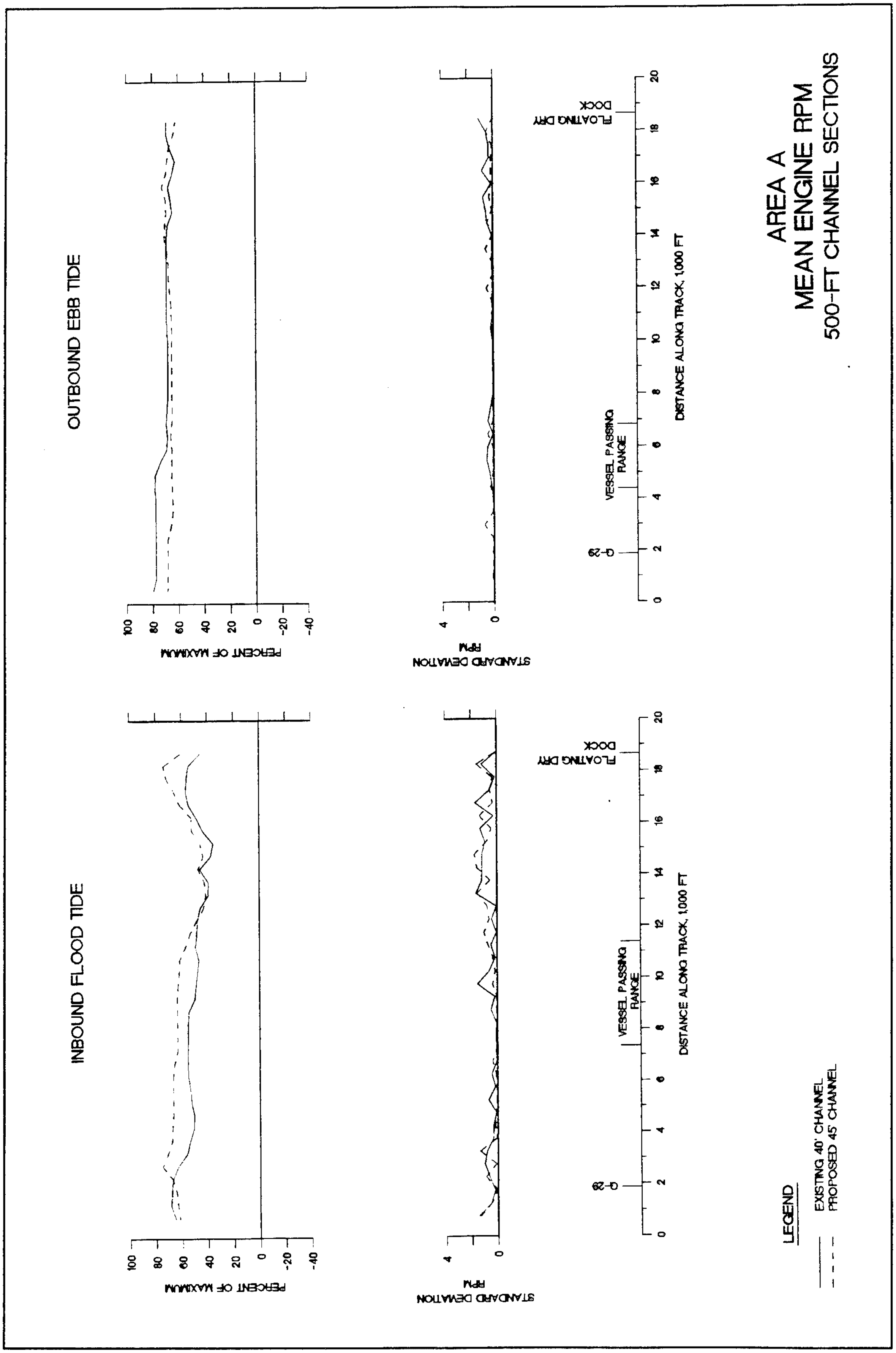

AREA A
MEAN MINIMUM STARBOARD EDGE CLEARANCE
500-FT CHANNEL SECTIONS
INBOUND FLOOD TIDE
OUTBOUND EBB TIDE
CLEARANCE IN FEET
STANDARD DEVIATION
DISTANCE ALONG TRACK, 1,000 FT
Q-29
VESSEL PASSING RANGE
FLOATING DRY DOCK
LEGEND
EXISTING 40' CHANNEL
PROPOSED 45' CHANNEL

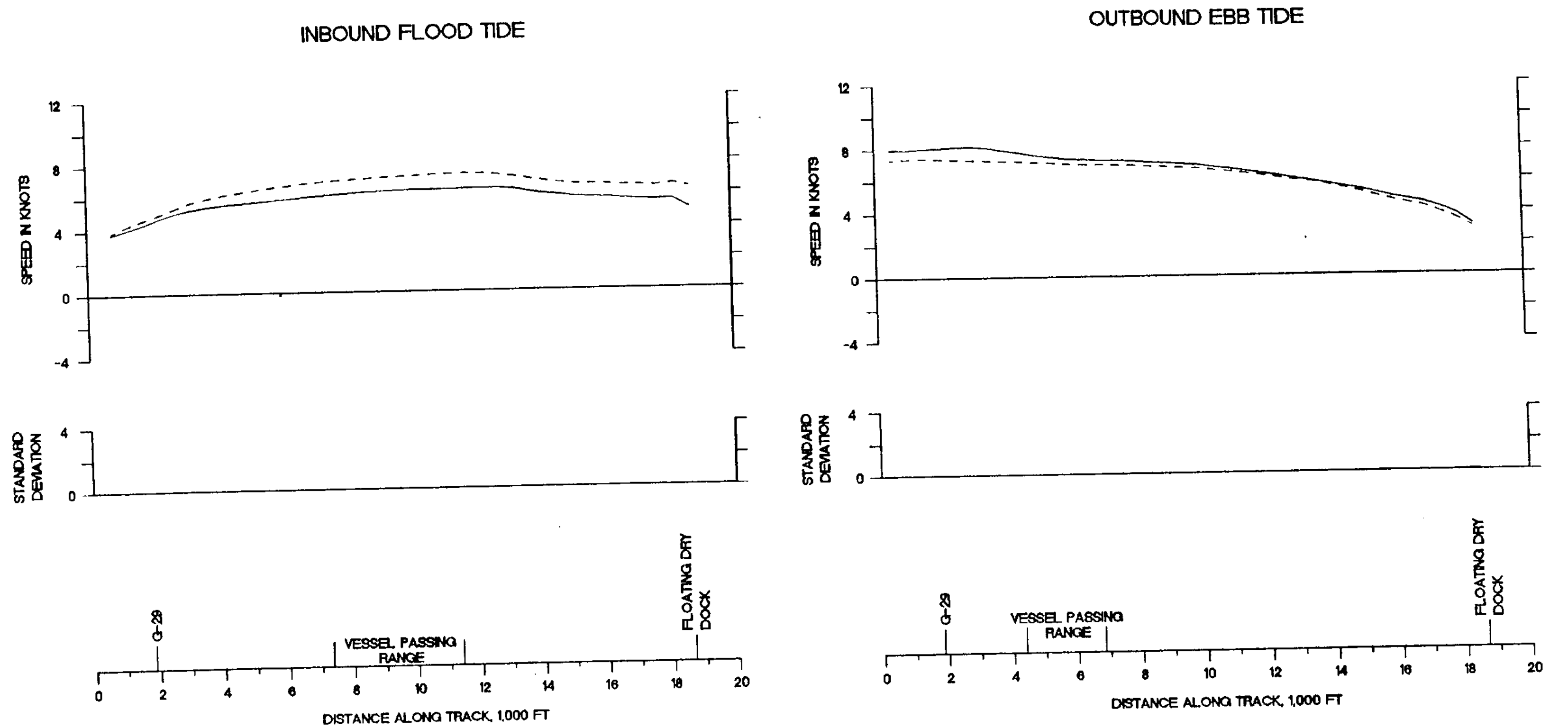


LEGEND

—— EXISTING 40' CHANNEL
- - - PROPOSED 45' CHANNEL

AREA A
MEAN RUDDER ANGLE
500-FT CHANNEL SECTIONS

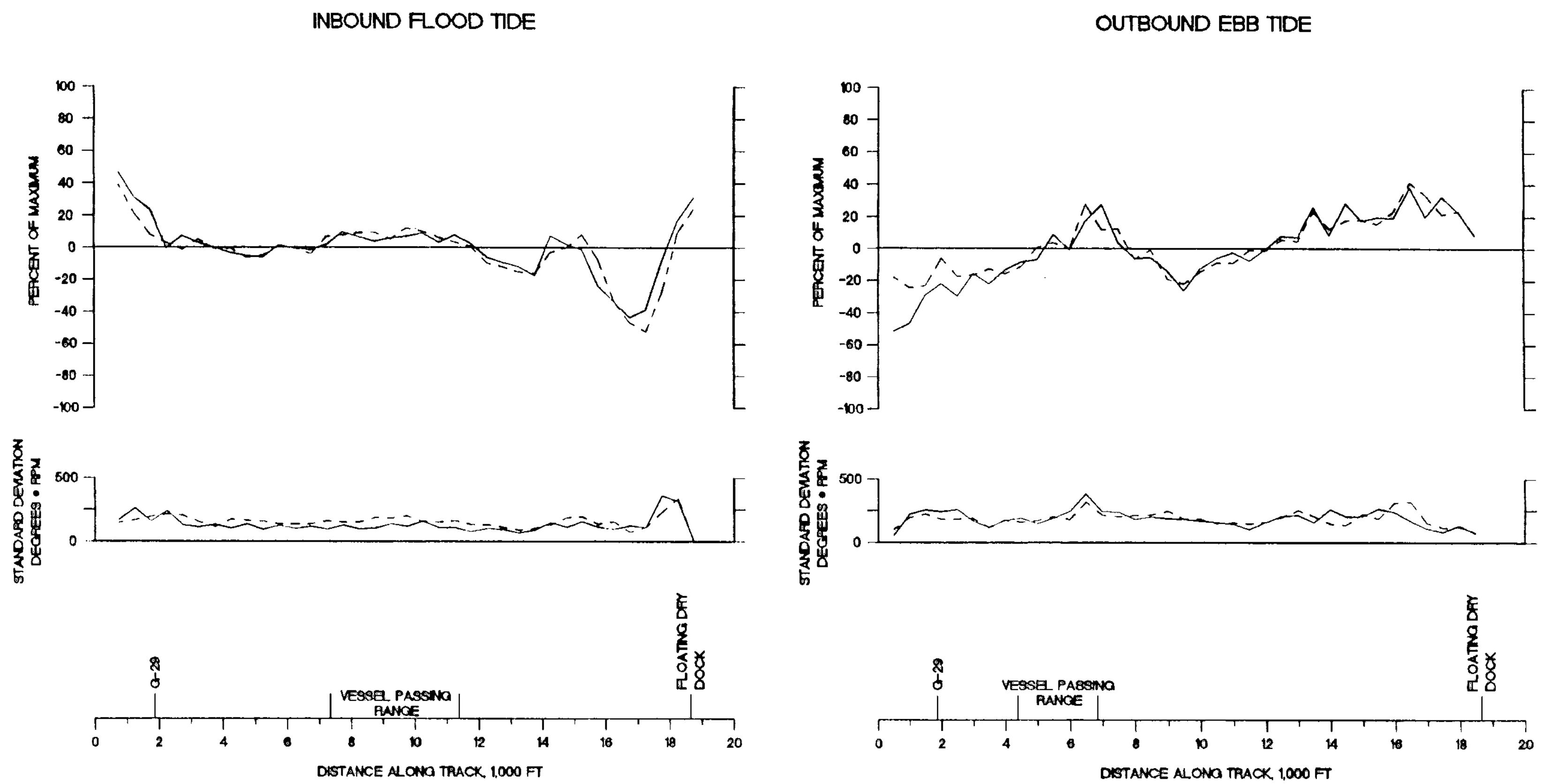

AREA A
MEAN ENGINE RPM
500-FT CHANNEL SECTIONS
INBOUND FLOOD TIDE
OUTBOUND EBB TIDE
PERCENT OF MAXIMUM
STANDARD DEVIATION RPM
DISTANCE ALONG TRACK, 1,000 FT
VESSEL PASSING RANGE
FLOATING DRY DOCK
G-29
LEGEND
EXISTING 40' CHANNEL
PROPOSED 45' CHANNEL



LEGEND

—— EXISTING 40' CHANNEL
– – – PROPOSED 45' CHANNEL

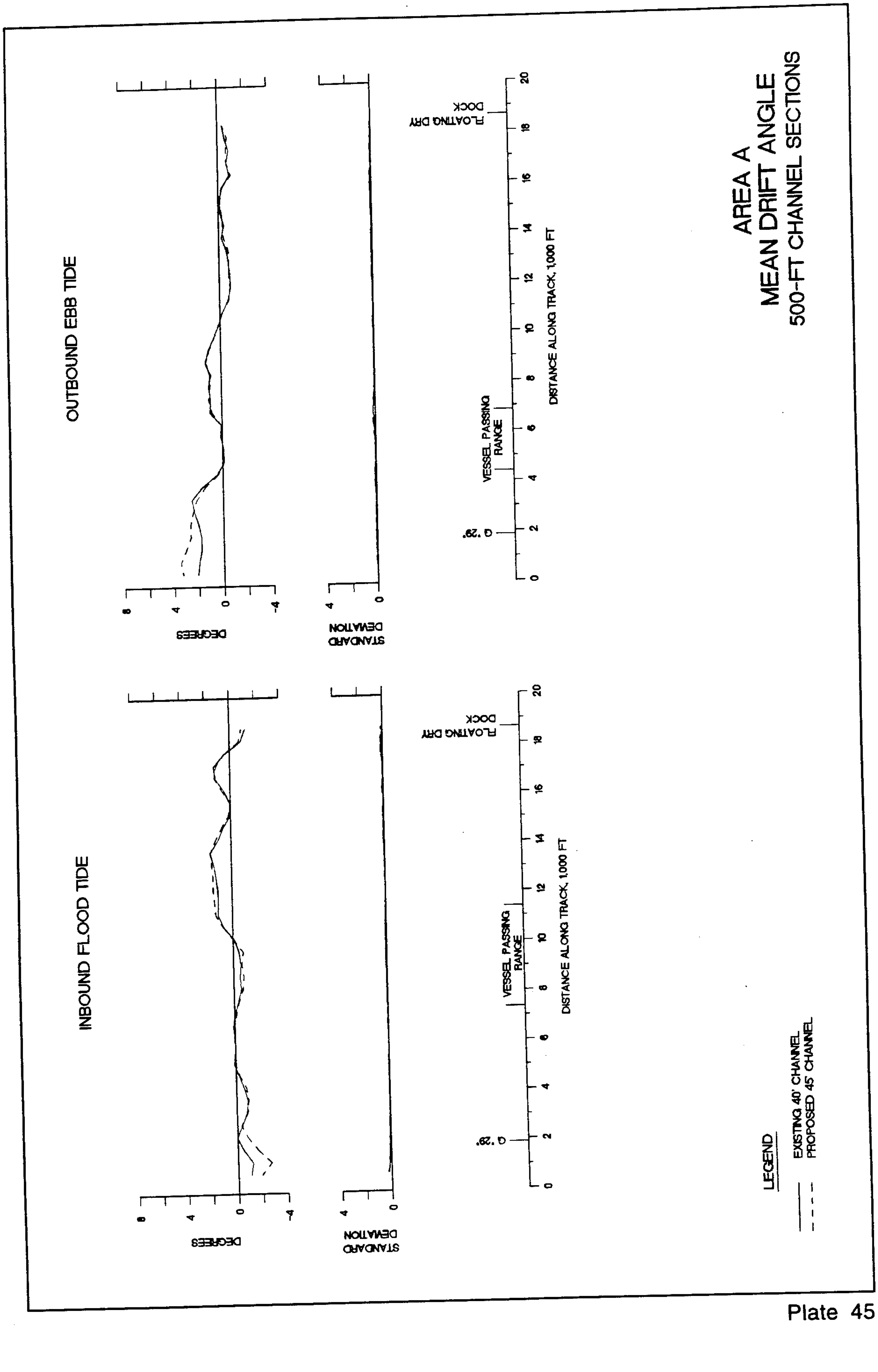
AREA A
MEAN SHIP SPEED
500-FT CHANNEL SECTIONS

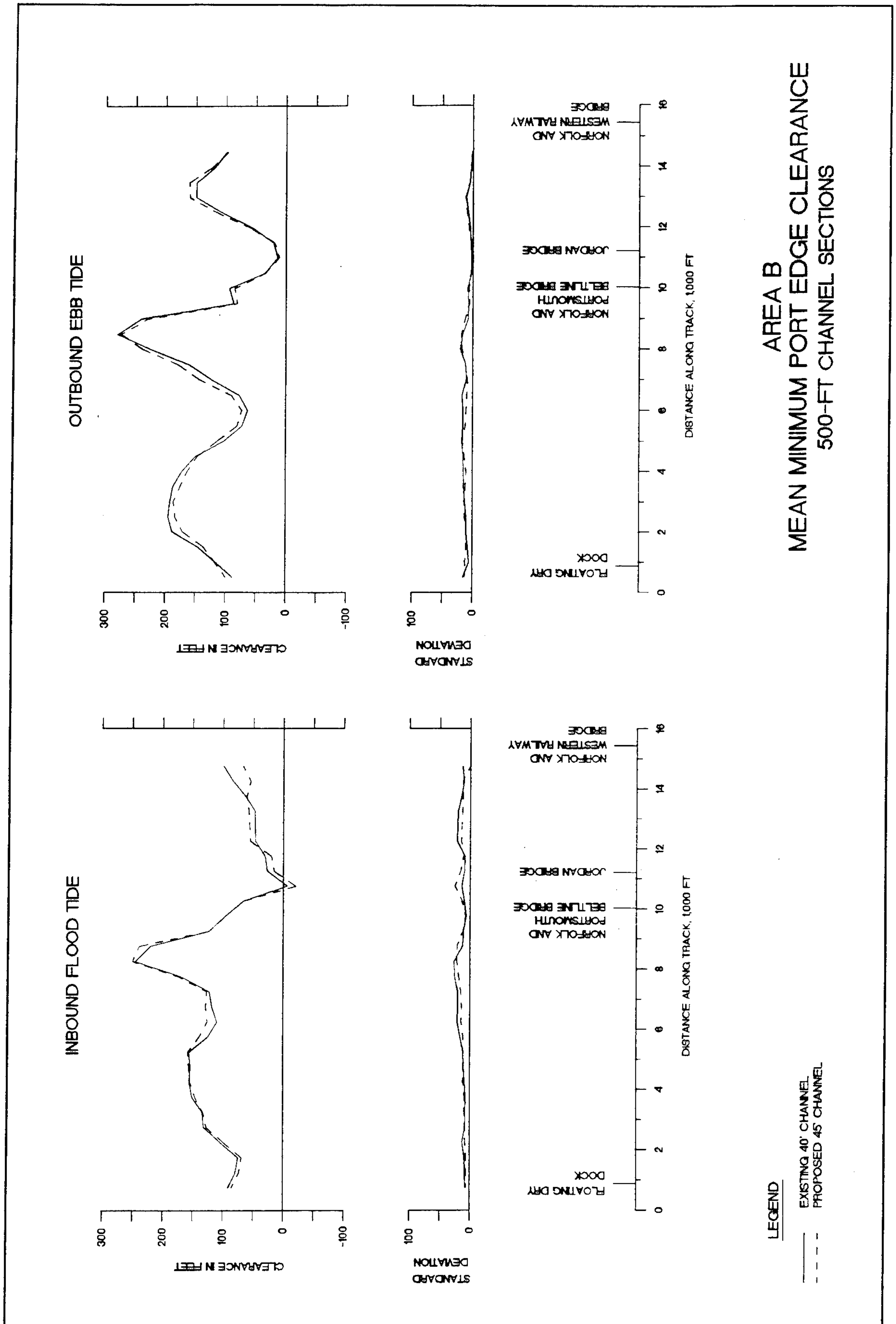


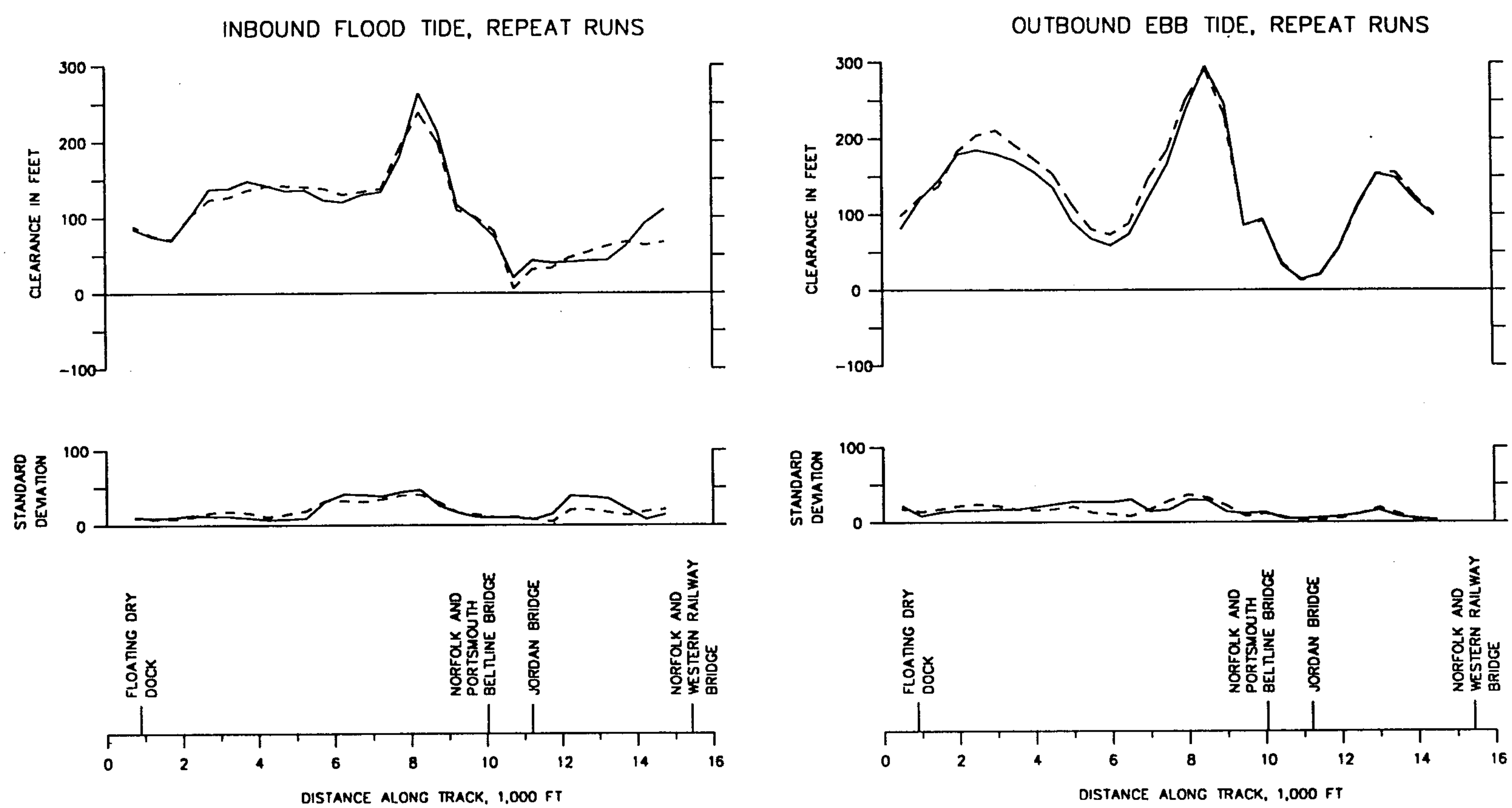
LEGEND

—— EXISTING 40' CHANNEL
- - - PROPOSED 45' CHANNEL

AREA A
MEAN MANEUVERING FACTOR
500-FT CHANNEL SECTIONS


OUTBOUND EBB TIDE
INBOUND FLOOD TIDE
DEGREES
STANDARD DEVIATION
DISTANCE ALONG TRACK, 1,000 FT
VESSEL PASSING RANGE
FLOATING DRY DOCK
G '29'
LEGEND
EXISTING 40' CHANNEL
PROPOSED 45' CHANNEL
AREA A
MEAN DRIFT ANGLE
500-FT CHANNEL SECTIONS

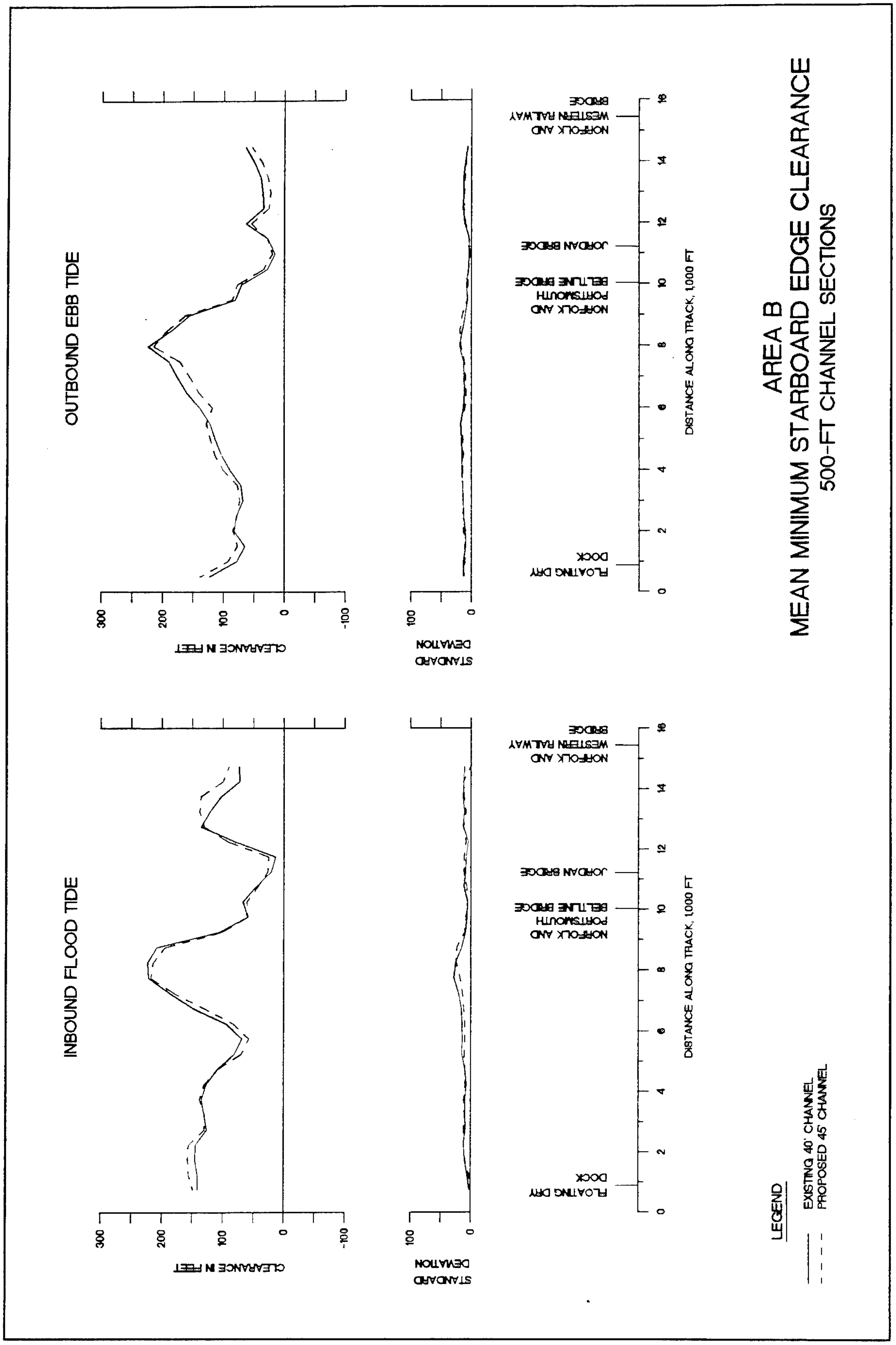

AREA B
MEAN MINIMUM PORT EDGE CLEARANCE
500-FT CHANNEL SECTIONS
INBOUND FLOOD TIDE
OUTBOUND EBB TIDE
CLEARANCE IN FEET
STANDARD DEVIATION
DISTANCE ALONG TRACK, 1,000 FT
FLOATING DRY DOCK
NORFOLK AND PORTSMOUTH BELTLINE BRIDGE
JORDAN BRIDGE
NORFOLK AND WESTERN RAILWAY BRIDGE
LEGEND
EXISTING 40' CHANNEL
PROPOSED 45' CHANNEL

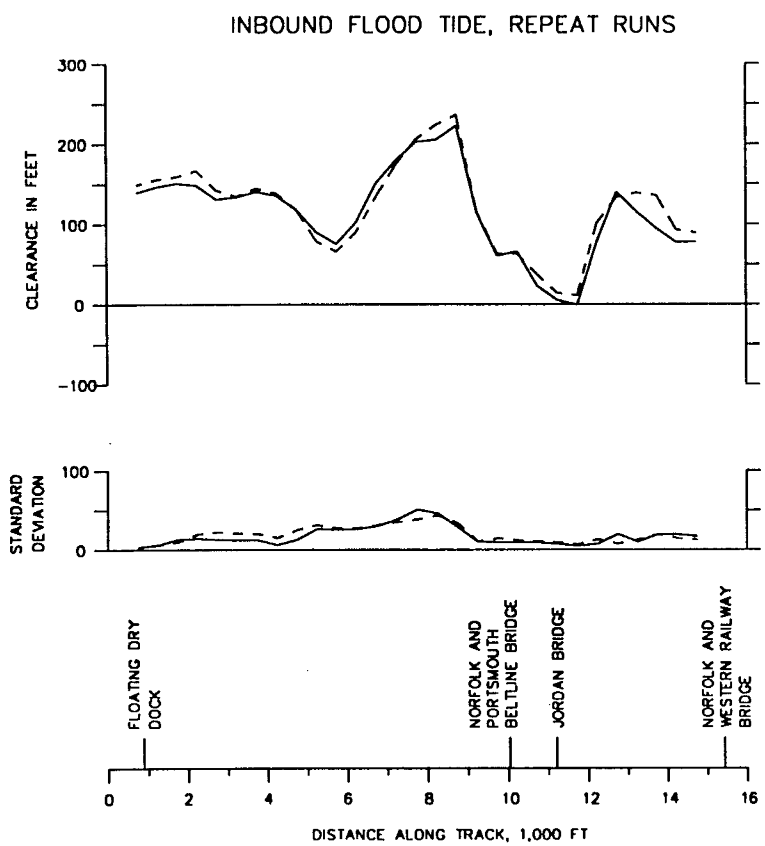


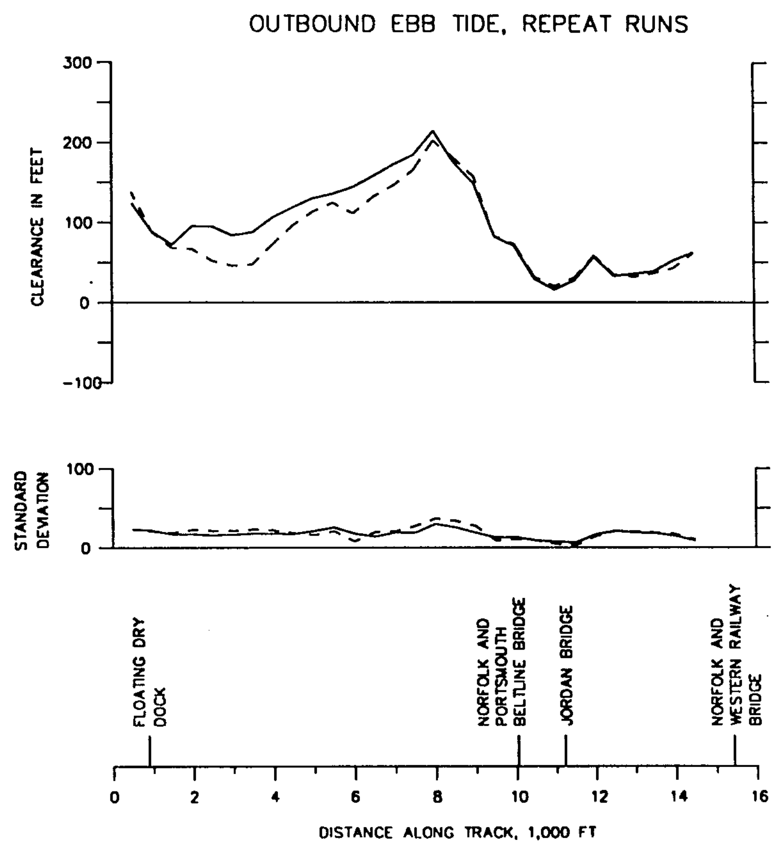
LEGEND

—— EXISTING 40' CHANNEL
- - - PROPOSED 45' CHANNEL

AREA B
MEAN MINIMUM PORT EDGE CLEARANCE
REPEAT RUNS ONLY
500-FT CHANNEL SECTIONS


AREA B
MEAN MINIMUM STARBOARD EDGE CLEARANCE
500-FT CHANNEL SECTIONS
INBOUND FLOOD TIDE
OUTBOUND EBB TIDE
CLEARANCE IN FEET
STANDARD DEVIATION
DISTANCE ALONG TRACK, 1,000 FT
FLOATING DRY DOCK
NORFOLK AND PORTSMOUTH BELTLINE BRIDGE
JORDAN BRIDGE
NORFOLK AND WESTERN RAILWAY BRIDGE
300
200
100
0
-100
0
2
4
6
8
10
12
14
16
LEGEND
EXISTING 40' CHANNEL
PROPOSED 45' CHANNEL

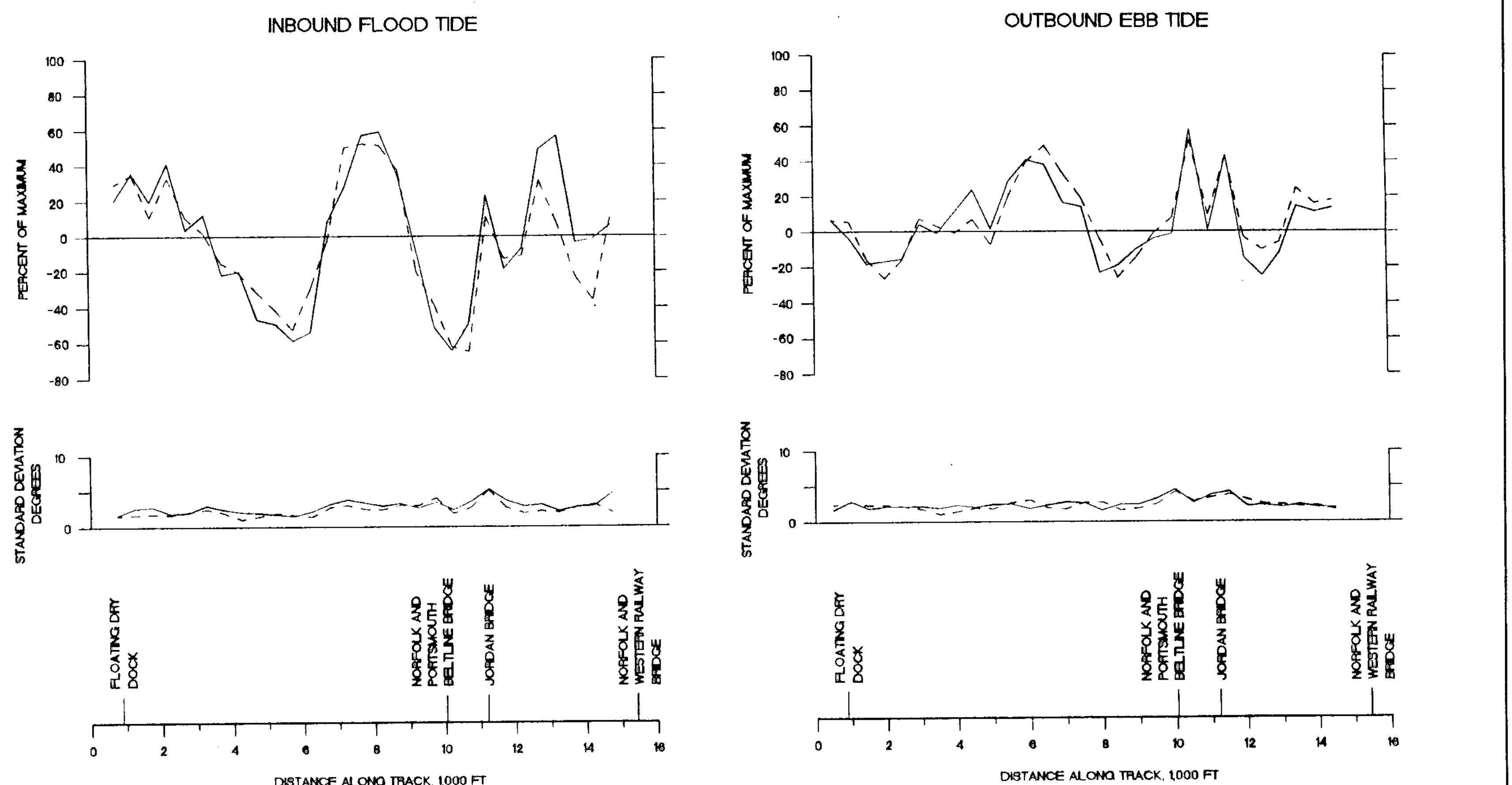




LEGEND

——— EXISTING 40' CHANNEL
- - - - PROPOSED 45' CHANNEL

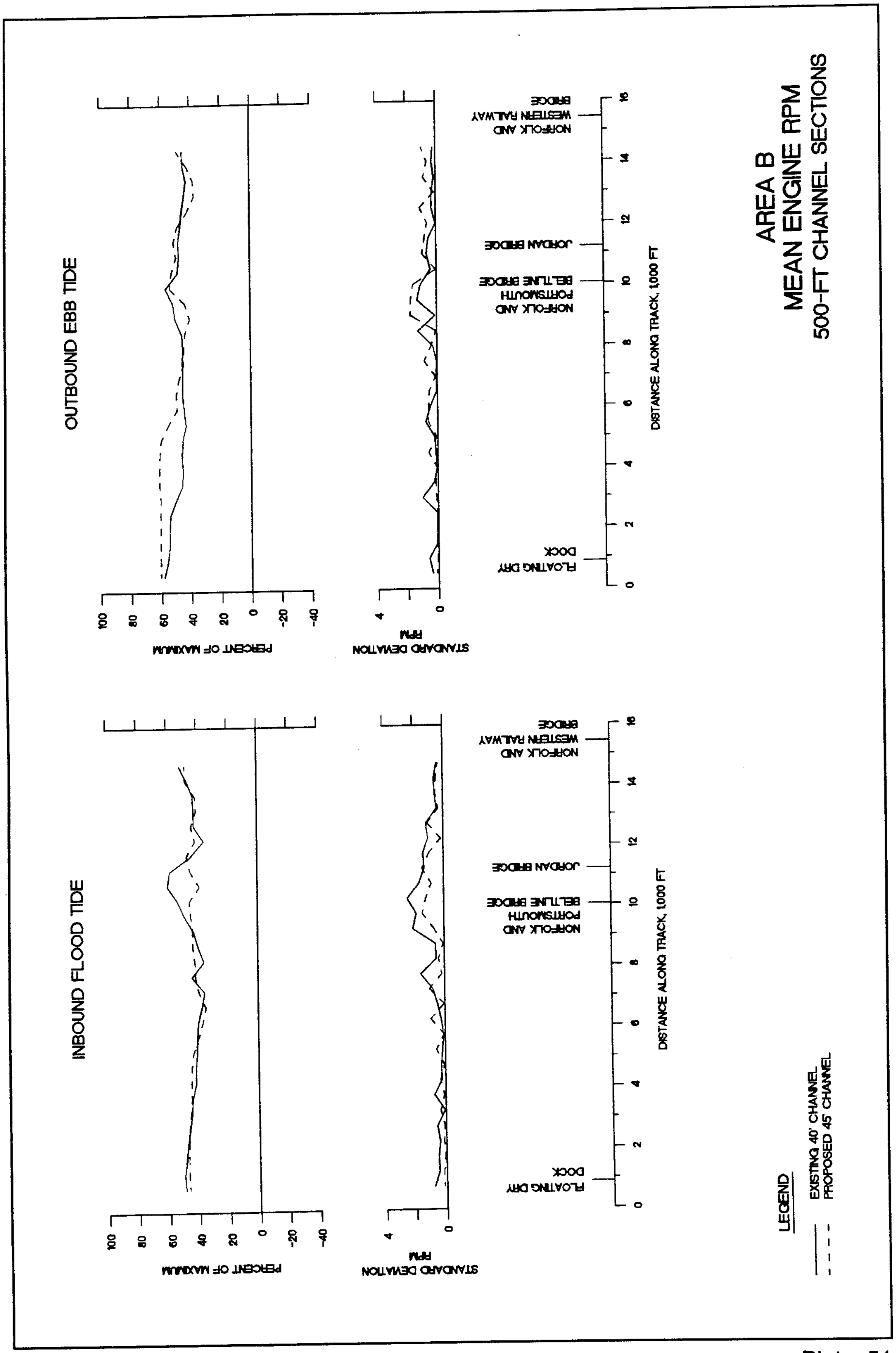
AREA B
MEAN MINIMUM STARBOARD EDGE
CLEARANCE
REPEAT RUNS ONLY
500-FT CHANNEL SECTIONS

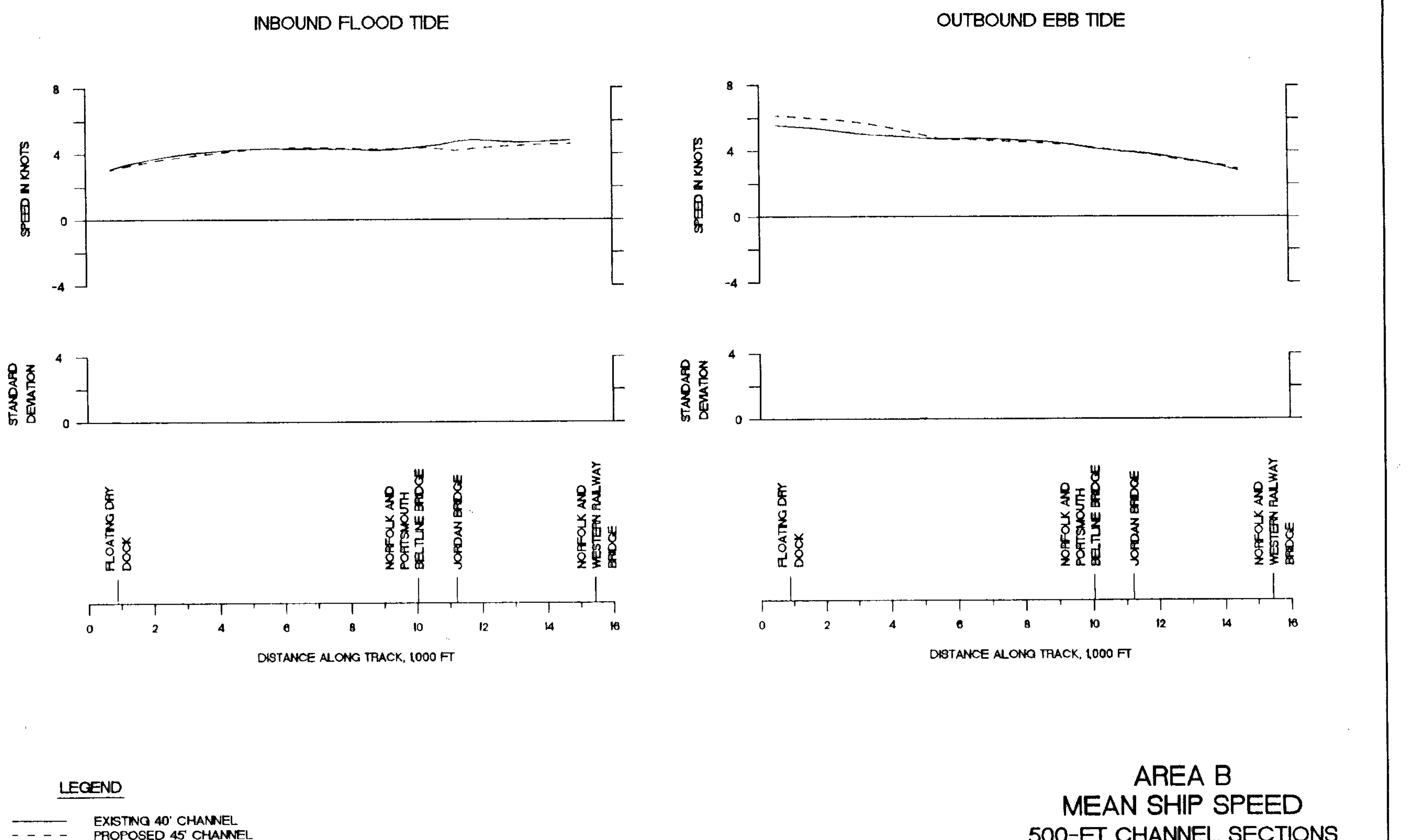


LEGEND

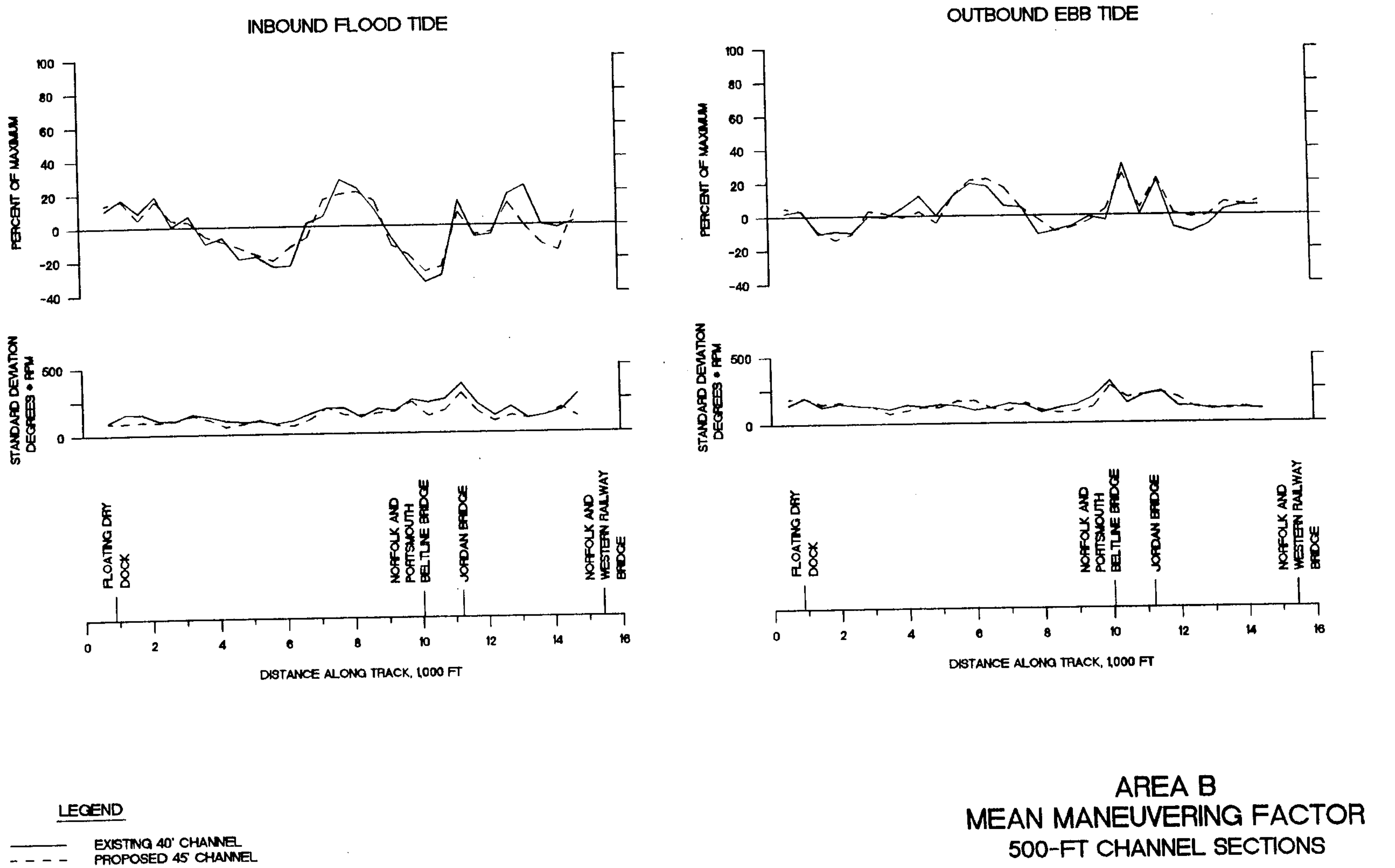
EXISTING 40' CHANNEL
PROPOSED 45' CHANNEL

AREA B
MEAN RUDDER ANGLE
500-FT CHANNEL SECTIONS


AREA B
MEAN ENGINE RPM
500-FT CHANNEL SECTIONS
INBOUND FLOOD TIDE
OUTBOUND EBB TIDE
PERCENT OF MAXIMUM
STANDARD DEVIATION RPM
DISTANCE ALONG TRACK, 1000 FT
FLOATING DRY DOCK
NORFOLK AND PORTSMOUTH BELTLINE BRIDGE
JORDAN BRIDGE
NORFOLK AND WESTERN RAILWAY BRIDGE
LEGEND
EXISTING 40' CHANNEL
PROPOSED 45' CHANNEL



AREA B
MEAN SHIP SPEED
500-FT CHANNEL SECTIONS



AREA B
MEAN MANEUVERING FACTOR
500-FT CHANNEL SECTIONS

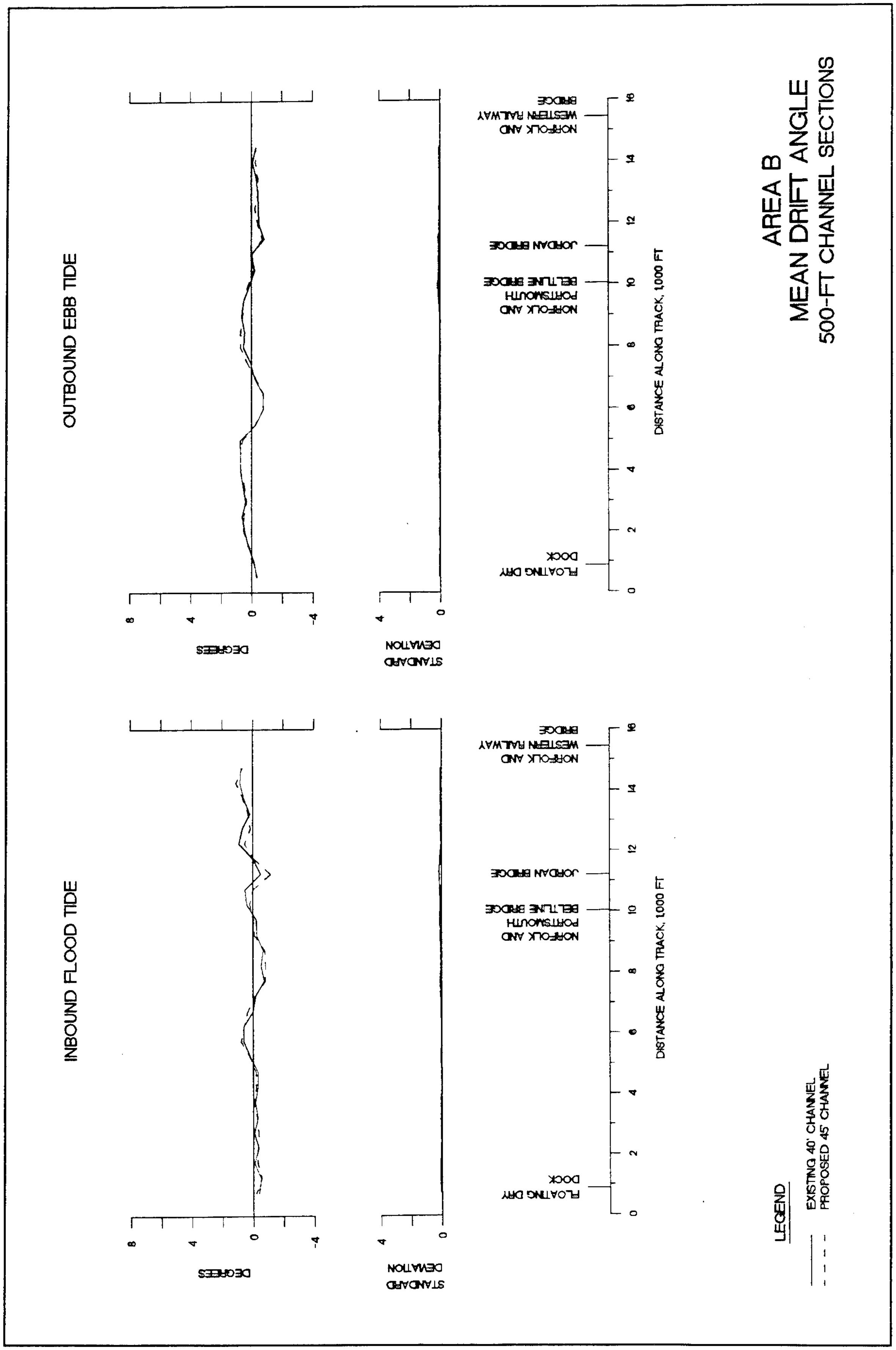
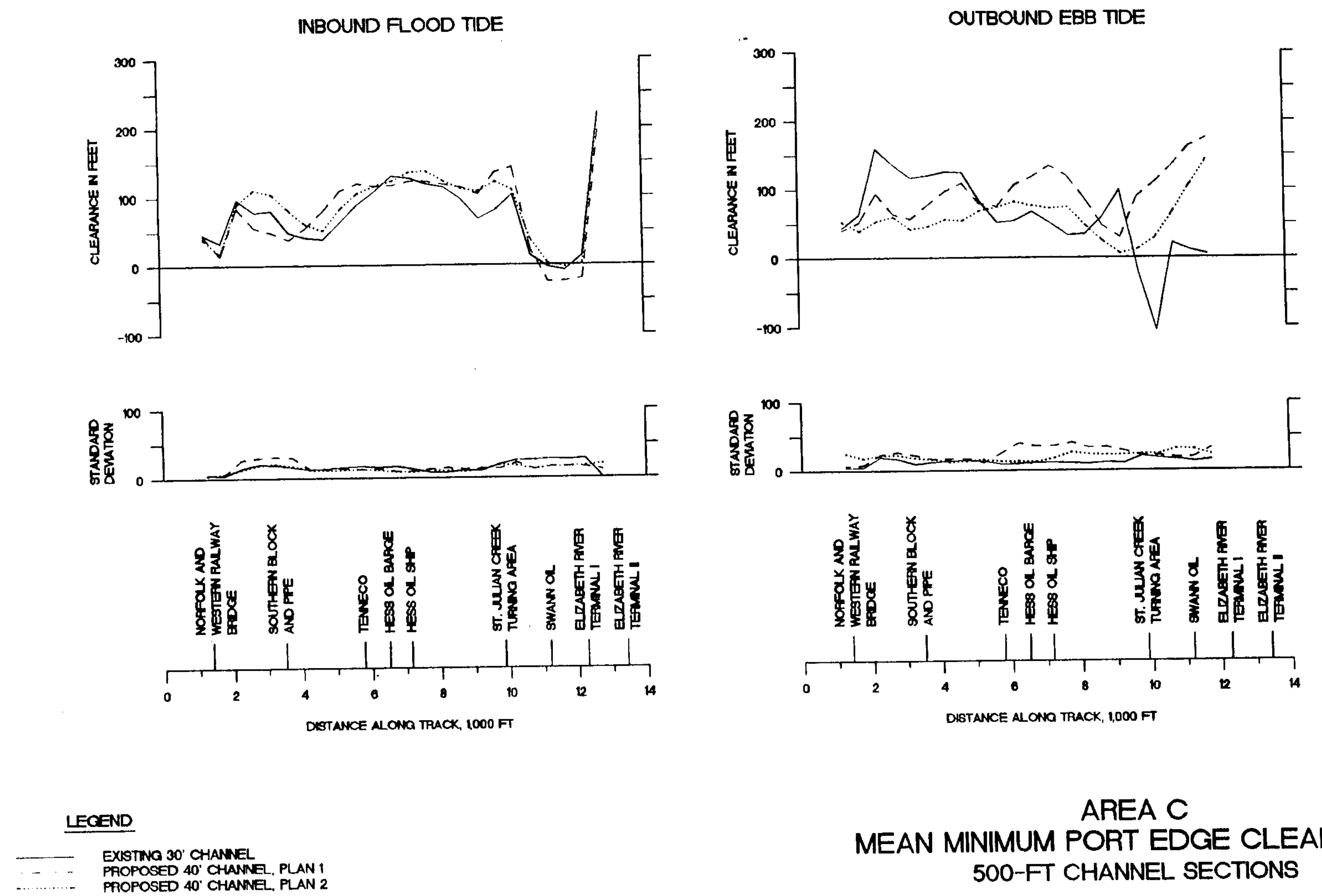
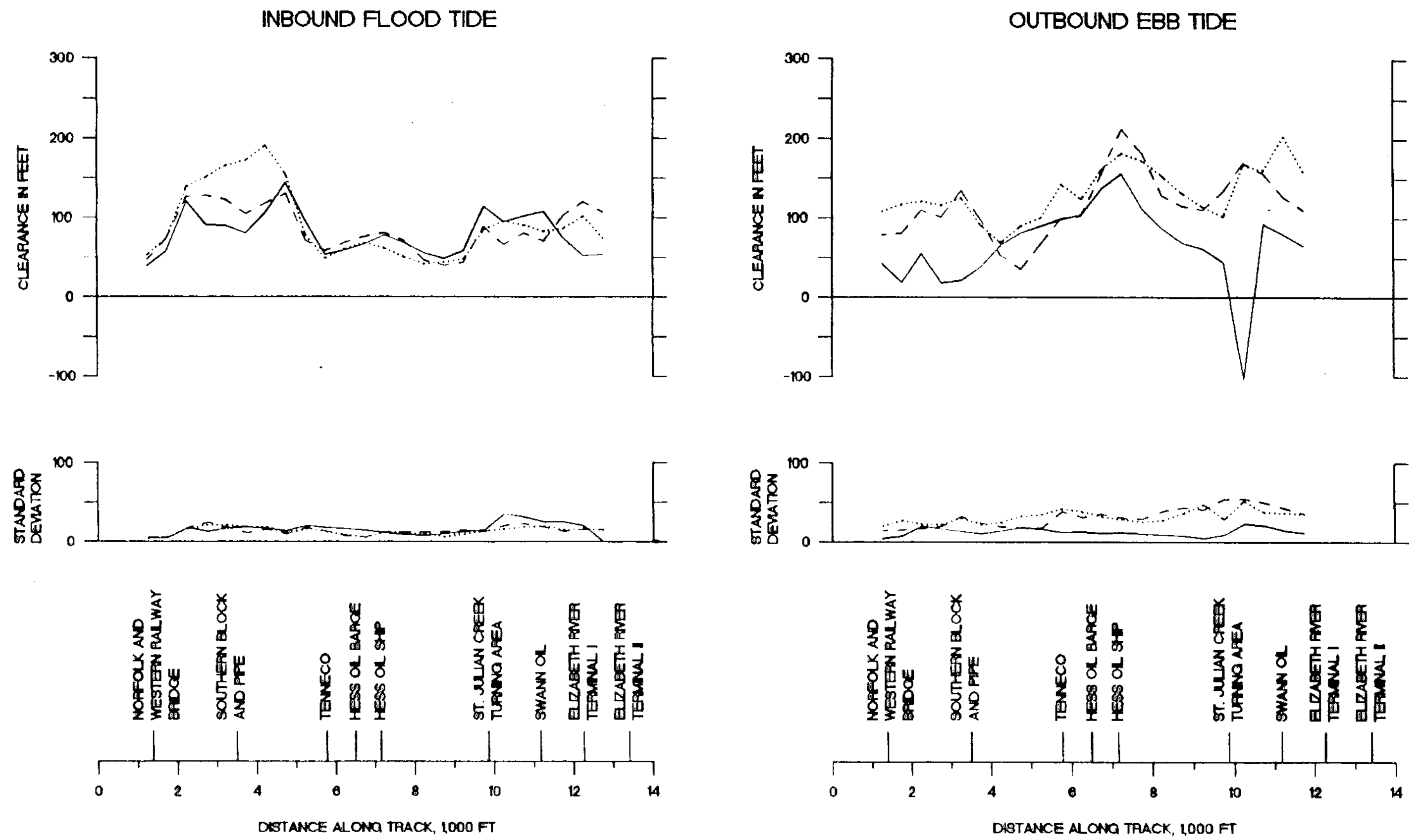

AREA B
MEAN DRIFT ANGLE
500-FT CHANNEL SECTIONS
INBOUND FLOOD TIDE
OUTBOUND EBB TIDE
DEGREES
STANDARD DEVIATION
DISTANCE ALONG TRACK, 1000 FT
FLOATING DRY DOCK
NORFOLK AND PORTSMOUTH BELTLINE BRIDGE
JORDAN BRIDGE
NORFOLK AND WESTERN RAILWAY BRIDGE
LEGEND
EXISTING 40' CHANNEL
PROPOSED 45' CHANNEL

Plate 54



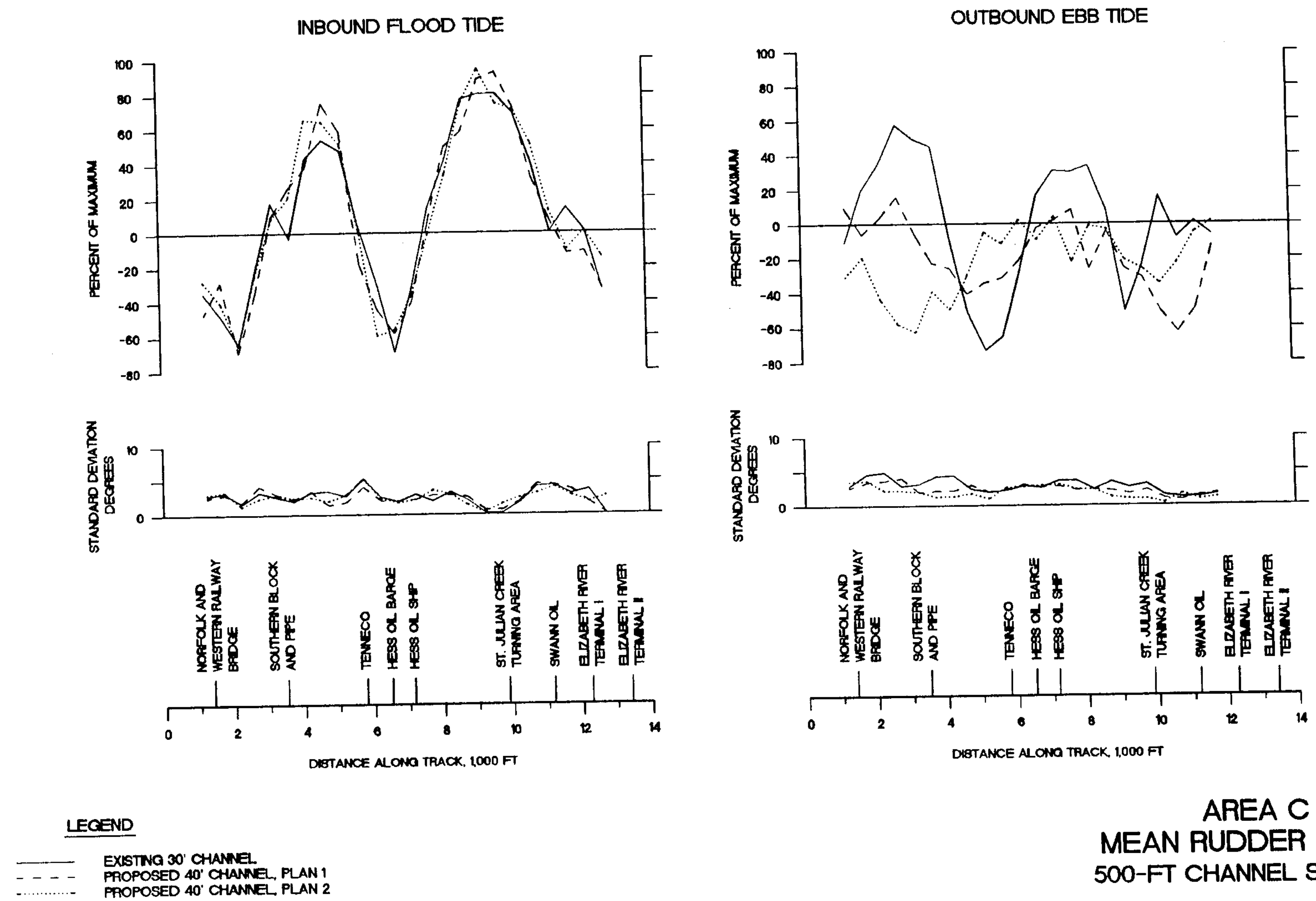
AREA C
MEAN MINIMUM PORT EDGE CLEARANCE
500-FT CHANNEL SECTIONS



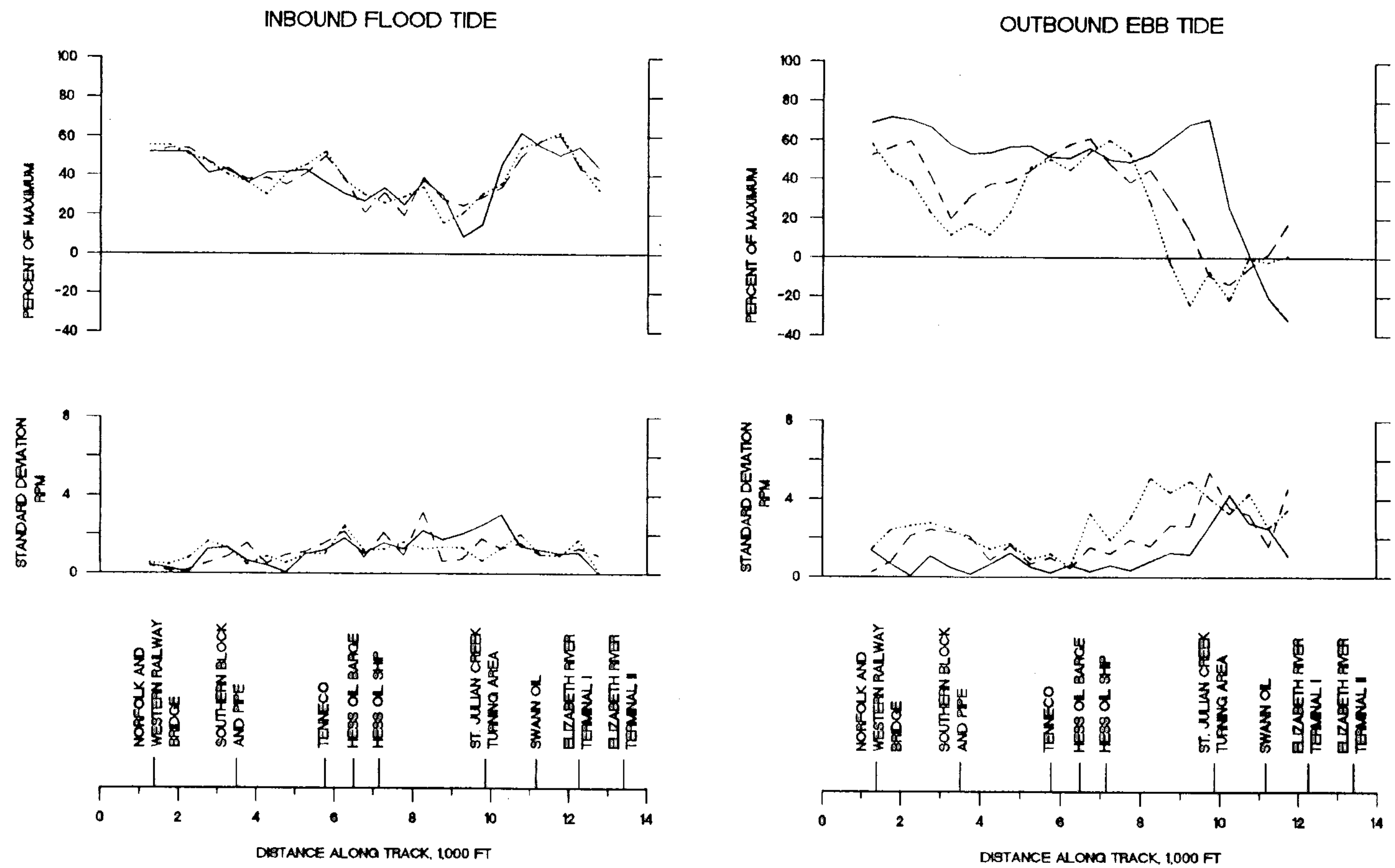
LEGEND

EXISTING 30' CHANNEL
PROPOSED 40' CHANNEL, PLAN 1
PROPOSED 40' CHANNEL, PLAN 2

AREA C
MEAN MINIMUM STARBOARD EDGE CLEARANCE
500-FT CHANNEL SECTIONS



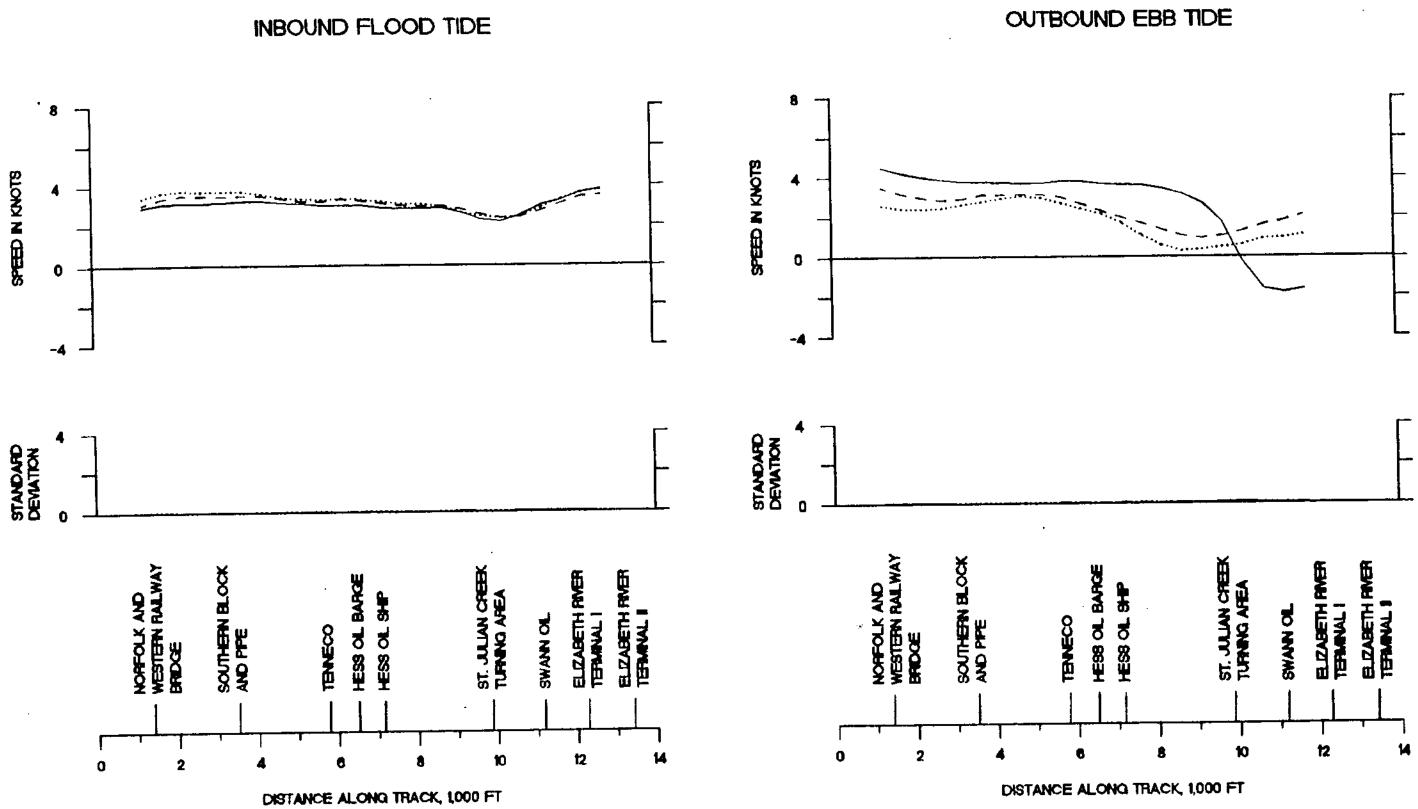
AREA C
MEAN RUDDER ANGLE
500-FT CHANNEL SECTIONS



LEGEND

EXISTING 30' CHANNEL
PROPOSED 40' CHANNEL, PLAN 1
PROPOSED 40' CHANNEL, PLAN 2

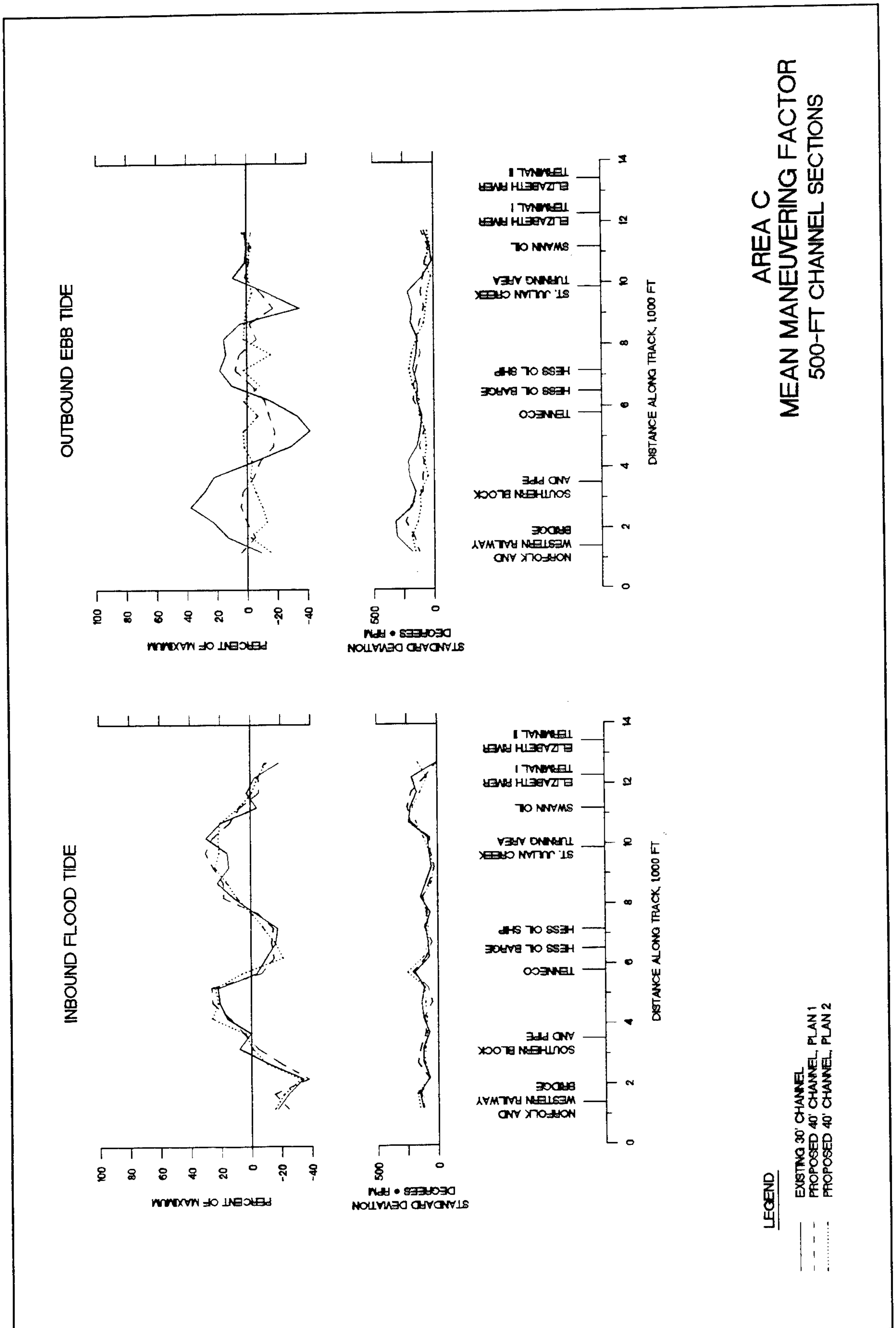
AREA C
MEAN ENGINE RPM
500-FT CHANNEL SECTIONS

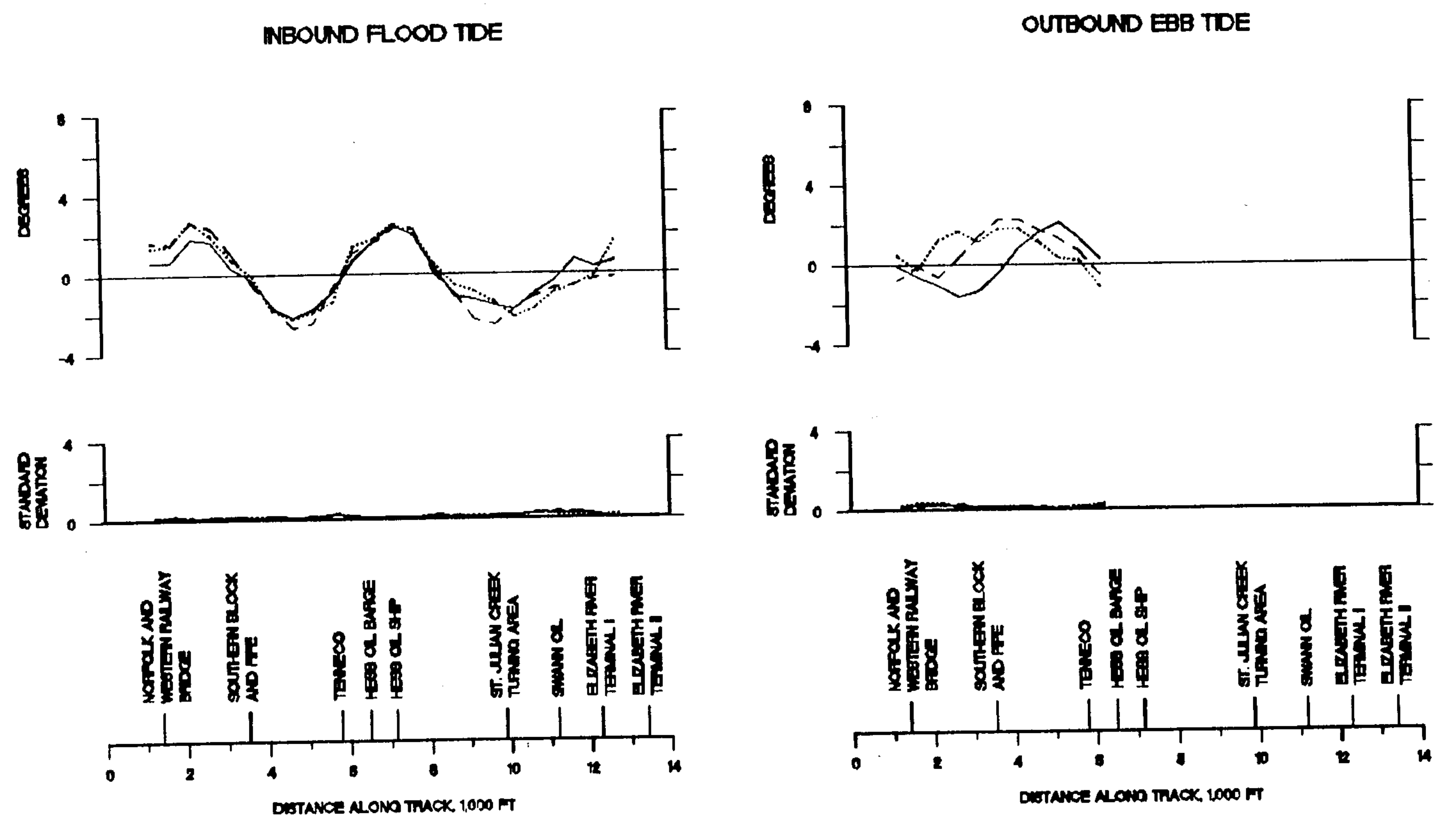


LEGEND

EXISTING 30' CHANNEL
PROPOSED 40' CHANNEL, PLAN 1
PROPOSED 40' CHANNEL, PLAN 2

AREA C
MEAN SHIP SPEED
500-FT CHANNEL SECTIONS


AREA C
MEAN MANEUVERING FACTOR
500-FT CHANNEL SECTIONS
INBOUND FLOOD TIDE
OUTBOUND EBB TIDE
PERCENT OF MAXIMUM
STANDARD DEVIATION DEGREES • RPM
DISTANCE ALONG TRACK, 1000 FT
NORFOLK AND WESTERN RAILWAY BRIDGE
SOUTHERN BLOCK AND PIPE
TENNECO
HESS OIL BARGE
HESS OIL SHIP
ST. JULIAN CREEK TURNING AREA
SWANN OIL
ELIZABETH RIVER TERMINAL I
ELIZABETH RIVER TERMINAL II
LEGEND
EXISTING 30' CHANNEL
PROPOSED 40' CHANNEL, PLAN 1
PROPOSED 40' CHANNEL, PLAN 2



LEGEND

EXISTING 30' CHANNEL
PROPOSED 40' CHANNEL, PLAN 1
PROPOSED 40' CHANNEL, PLAN 2

AREA C
MEAN DRIFT ANGLE
500-FT CHANNEL SECTIONS

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Dennis W. Webb
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13. ABSTRACT *(Maximum 200 words)*

The Elizabeth River Channel is the southernmost part of the Norfolk Harbor Channel. The Norfolk Harbor Channel joins with the 55-ft Newport News Channel to provide access to the Chesapeake Bay via the 55-ft Thimble Shoal Channel and to the Atlantic Ocean. The U.S. Army Engineer District, Norfolk, has proposed that a portion of the Elizabeth River be deepened to allow deeper drafted ships to use the port. In addition to deepening the channels by 5 ft, the District also proposed to build a turning basin near the Elizabeth River Terminals.

These proposed improvements were tested using the U.S. Army Engineer Waterways Experiment Station (WES) ship/tow simulator, located in Vicksburg, MS. Docking pilots traveled to WES to operate the model. Effects modeled included currents and two-way traffic.

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